TELESCOPE MAKING 22

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The magazine *for*, *by*, and *about* telescope makers!

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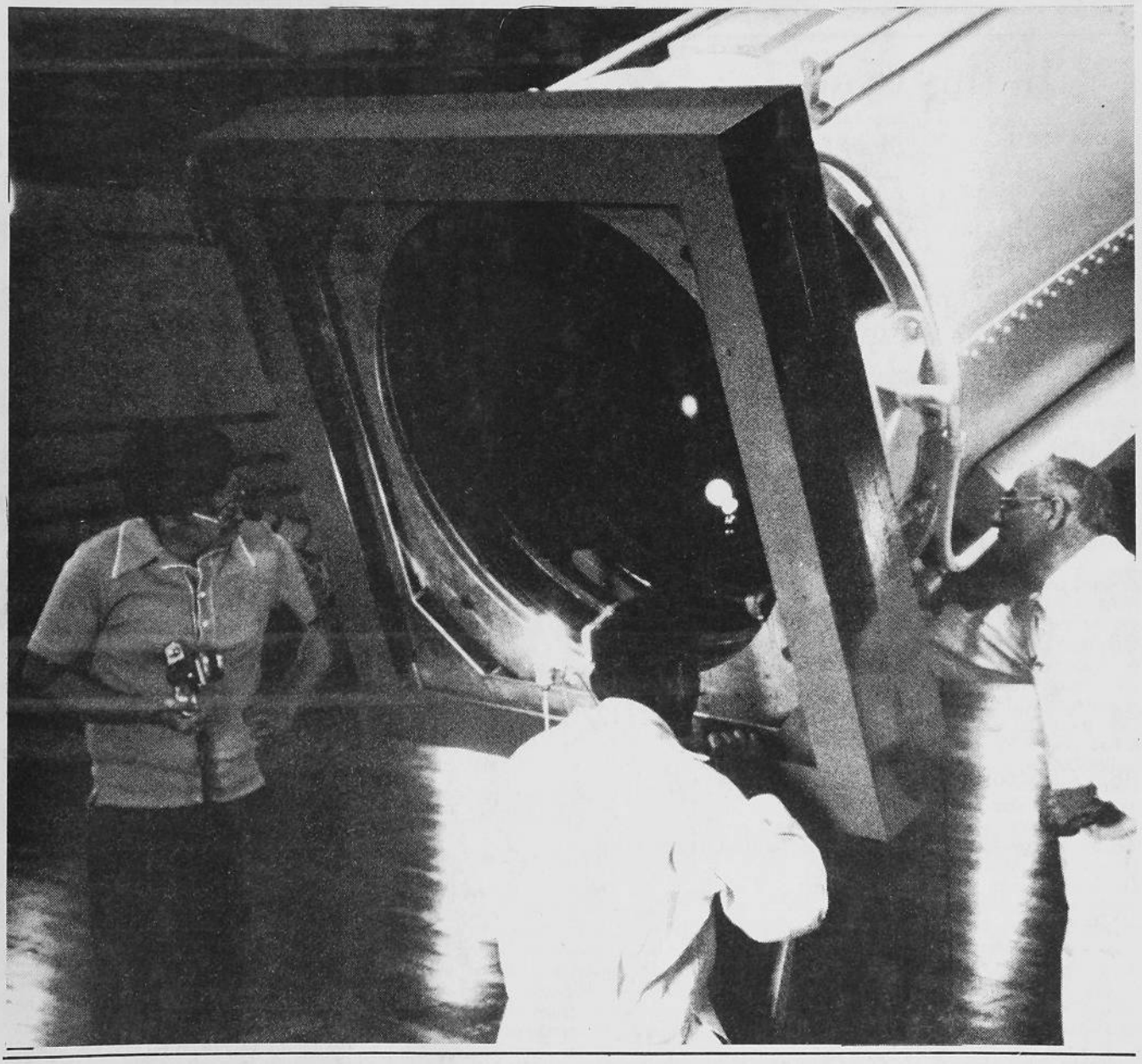

TELESCOPE MAKING

The magazine *for, by,* and *about* telescope makers!

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Editorial

I have often wondered how many telescopes are consigned to attics and cellars — no longer used — in various personal scrap heaps around the country. Many of you readers probably wonder, too. Lots of avid telescope makers have mirrors tucked away in boxes, mirrors they will never again use. What a waste! These optical orphans come to mind every Christmas when I receive calls from local persons seeking an instrument as a present for a youngster or spouse.

And all year long, I hear pleas from foreign amateurs who cannot find the supplies to make a telescope or cannot afford instruments in their native countries. Americans often do not realize the restrictions placed on amateurs in foreign countries by government duties on imported optical equipment. Over the years I have tried, whenever possible, to honor requests from such amateurs. The results are often interesting. Back in the early 1950s I received a request for help from an American teaching in India. He wanted a 6″ mirror kit with which to build a telescope for his students — but customs there indicated that probably a heavy tax would be imposed on any such kit. We sidestepped this problem by sending him a kit (furnished by members of the Boston ATMs) labeled as an "educational toy!"

In a South American country, a local amateur had serious customs difficulties. It seems there were no fixed charges on imported items, so the local custom agent would charge whatever he believed he could get away with. In his original letter to me, this amateur indicated that locally an imported item could be charged more than 100% the

original American price! Fortunately, he was able to send me American dollars, so I purchased the items for him and sent them as a "gift" with no declared value. Recently, another amateur needed Teflon for a Dobsonian mounting, but local costs were too high for the telescope makers. I solved this by sending him a sheet of Teflon as a stiffener for an envelope containing some telescope pictures.

This "cloak and dagger" approach is annoying — and one person cannot ever hope to help all those in need of astronomical assistance. What is needed is a group effort carefully organized to really accomplish some good. I propose a clearinghouse be established — a central place with which American amateurs can list telescopes, optics, or equipment they are willing to donate or make available at a minimum cost to those less fortunate than they are. This organization would service any amateur, in this country or in foreign ones, by sending the list of available items and charges. It would be a problem to ship completely mounted telescopes overseas, especially large aperture ones, but optics and plans could be sent in these cases. A copy of *How to Build a Dobsonian Telescope* plus several pieces of Teflon (hard to get outside this country) would allow amateurs almost anywhere to complete a working instrument.

How to accomplish this project? Who could do it? A big-city astronomical society of amateurs and telescope makers might attempt it and find the work and joy of helping others made it worthwhile. The Astronomical League, with its large affiliation of groups, is an ideal clearinghouse to set up such an endeavor, with local society members doing the work. The Western Amateurs is yet another group qualified for such a venture if they cared to participate, perhaps in a combined effort with the Astronomical League.

These groups might, in turn, approach the United Nations educational sections who would help send instruments and optics to foreign countries. But even here in the States, think of the schools, scouts, handicapped who could benefit from those unused telescopes!

Perhaps the first step should be a survey to see if there is enough interest. I am asking you TM readers to approach anyone you know to find out how many telescopes or sets of optics you can find that are not being used and might be available to help spread the interest and hobby of astronomy and telescope making — then drop me a line. If enough equipment is located along with those willing to make it available to others, then we could give serious thought to trying to set up the clearinghouse.

Let's make 1984 the year in which the American amateurs advanced the frontier of "Help a newcomer get acquainted with observing and telescopes." Of course, this also applies to helping established amateurs get larger aperture optics so they can do more work in observing.

Robert E. Cox

Robert E. Cox
305 Linda Lane
O'Fallon, MO 63366

Letters

Hot Stuff for Diagonals

Dear Sir / Attached is a small scrap of zero-expansion material. And here is one of the experiments you can run. Hold one corner of the piece with a pliers. Heat another corner for about 20 seconds with a propane torch — until the area starts to redden up. Then plunge the piece into ice water. It will not crack.

If you hold the heated area in the flame long enough, the section will start to devitrify (turn white or crystallize) and soften. Then when you plunge the piece into ice water, it will crack along the border where devitrification has occurred, showing that you have altered its expansion properties.

Another experiment: Using a green silicon carbide grinding wheel at the rated rpm, shape the piece by hand into a circle or triangle or rectangle or other artistic shape. Note how easily it grinds, with only small flaking off of the corners. Try that with window glass, or Pyrex, or even quartz!

We sell $^{15}/_{16}$" and $1\frac{3}{8}$" minor axis diagonals made of zero-expansion material, $^{5}/_{16}$"-thick, $^{1}/_{8}$-wave flat, silvered and overcoated, for $30 and $45 respectively. We trust they will handle most of your needs.

Augen Optics
947 Parkside Lane
Lancaster, PA 17601

— Okay, they get a free plug! This stuff is pretty neat. Send for your own free sample.

Eggcrate Blanks

Dear Richard / Enclosed are copies of information I recently received from United Lens on large blanks. I think we'd all benefit if you would include this information in a future issue of TM so that others will be aware of what is available. Anyone interested in an Eggcrate blank similar to the one I displayed at the most recent Stellafane should contact optician Gene Fair, 1258 N. San Antonio Ave., Pomona, CA 91767; phone (714) 620-5515. Gene's prices are better than the manufacturer's and he can obtain them in diameters up to 30".

John A. Vogt
245 Franklin Ave.
Franklin Square, NY 11010

— Quoting directly from the sales literature enclosed by John: "New Web Back Design Reduces Weight of Large Telescope Mirror By Nearly 40 Percent. It's the answer to the weight reduction requirements of telescope builders. This new web back design, developed and manufactured by United Lens Company, can be utilized for dramatic weight reduction of any front surface mirror blank, ranging in diameter from 4¼" to 20"." Then it goes on to say, "...in answer to weight concern traditionally expressed by telescope builders. Now, telescope markers [sic] will benefit in greater ease of handling and a significant weight reduction in the finished product.

"Custom sizes from your prints can be molded and shipped within five weeks. More good news: the same weight reducing web principle can be applied to other large glass moldings."

They also have sagged blanks up to 110" in diameter and up to $1\frac{5}{8}$" thick. "In this age of advanced optical technology, application of these large saggings as reflectors, windows and beam splitters is common."

Microcomputers in Astronomy

Dear TM readers / At the mention of microcomputers with respect to astronomy, one might first think of programs to predict planetary positions, display star positions for any year up to the year 9999, or perhaps some fancy analysis program. Among telescope makers, however, the mention of microcomputers will inevitably initiate a discussion of telescope control, with perhaps a little instrument control thrown in for good measure. Moving numbers and stuff around on a little screen with a microcomputer is okay for some folks, but moving a telescope or some astronomical instrument about with a microcomputer is much better from a real TM's viewpoint.

As might be expected, a sizeable group of amateur and professional TMs has been busily applying microcomputers to the control of astronomical telescopes and instruments. The 1.5-meter telescope at Cerro Tololo Interamerican Observatory (CTIO) is controlled by a microcomputer, as are 0.6-meter and 1.5-meter telescopes at the Astronomical Institute in Vienna, and a 5.5-meter radio telescope in South Carolina. Several amateur 16-inch telescopes, and a portable telescope that can be towed about, are controlled by microcomputers. Work is progressing on a microprocessor-controlled telescope for continuous automatic operation at the south pole. Photometers are automatically changing their own filters, recording their own data, and capturing the fast-paced action of occultations in millisecond frames. Apple, Commodore, S-100, STD, and Q-Bus microcomputers are all being used in these various control tasks.

Recently, all these topics and more were discussed at the "Microcomputers In

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Updating Newtonian Collimation

Fast Newtonian telescopes have a reputation for not resolving detail as well as other telescopes. This is generally blamed on the relatively large secondary obstruction. While this is certainly a factor, in most cases the real culprit is collimation. One serious collimation problem, and one which I feel needs more exposure, is the poor design of Newtonian optical mountings commonly found on the market.

I have often wondered why astrophotographers seldom, if ever, use Newtonians for guide telescopes, since it seems more convenient to have the guiding eyepiece at the upper end of the tube. While weight and bulk undoubtedly play a part, I suspect that in many cases they are afraid that a Newtonian guide telescope would not stay in collimation even for the duration of a long exposure. I refuse to believe that it is impossible to design a Newtonian telescope which will stay in collimation.

The other problem, and the one to which I address this article, is a general lack of understanding of Newtonian collimation, specifically the collimation of the secondary mirror.

Contrary to popular belief, Newtonian collimation is neither simple nor straightforward. The time-honored method of collimating Newtonians essentially involves looking into the focuser and adjusting the two mirrors until everything looks concentric. It is not, in fact, possible to make everything concentric. You can get pretty close with an f/ number of 8 or higher. Such long-focus Newtonians were pretty much the standard some years ago. This, coupled with the forgiving nature of the instrument, may explain why so little has been said about a more critical method of collimation required by today's fast Newtonians.

Let me begin by describing a perfectly collimated Newtonian system. We are assuming a straight primary tube with a primary mirror accurately centered on the tube axis, and a focuser whose axis intersects the tube axis at right angles: in other words, the standard Newtonian configuration.

The central (axial) ray — an impossible one in practice, but one which will serve for theoretical purposes — enters the mouth of the tube on the tube axis (see fig. 1) at point A, and follows the tube axis down to the primary mirror. Striking the primary mirror dead center (point B), it reverses direction, retracing its path along the tube axis until it encounters the secondary mirror at point C. This point is the intersection of the tube axis and the focuser axis. At this point, the ray is deflected 90° and proceeds directly along the focuser axis to the eyepiece (point D). I have drawn a extremely fast (f/2) system for clarity.

Fig. 1 shows that the secondary mirror face must include point C, and that the mirror must be inclined 45° to both the tube axis and the focuser axis in order to give the proper reflection to the light beam. The line defined by EG will contain the major axis of the elliptical face of the secondary. The minor axis of the ellipse is in the third (unseen) dimension ad will be perpendicular to both the tube axis and the focuser axis. The secondary mirror would thus be seen edge-on in fig. 1. Any deviation from this plane will result in an off-axis image, a tilted focal plane, or both.

In light of these requirements, one wonders why most commercial secondary holders are made to tilt several degrees in all directions. Only three degrees of freedom — rotation about and translation along the axis of the tube and tilt angle — are required.

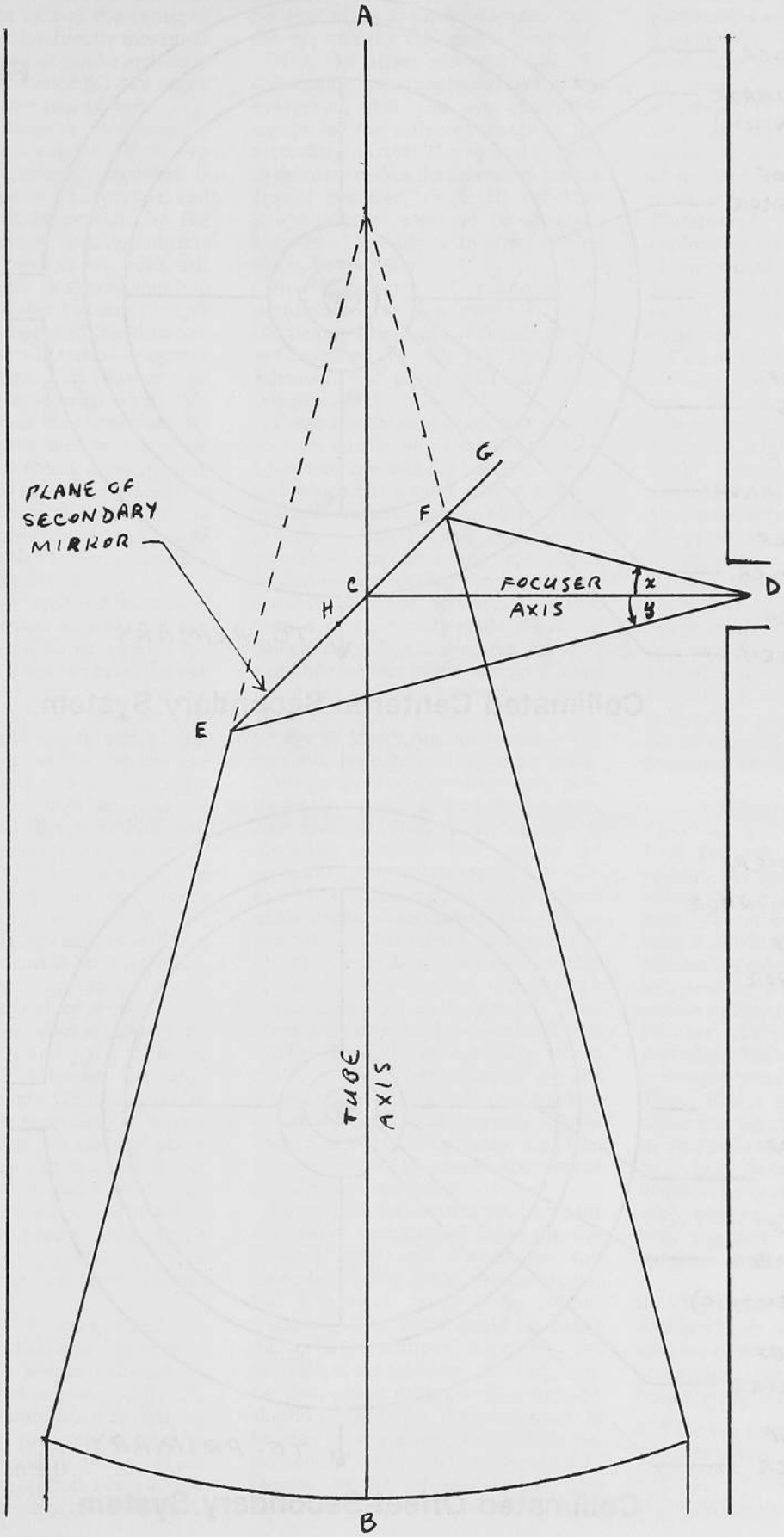
There are a variety of possible positions for the secondary which do not violate the aforementioned restrictions. However, there are only two commonly used methods of mounting the secondary mirror — each requiring its own collimation procedure and each with an associated and complicating optical illusion, which I will describe later.

Referring again to fig. 1, note that the distance from E to C is not the same as the distance from C to F. Consequently, if the secondary is to intercept only the returning light beam, the center of the secondary must fall not on the tube axis at point C, but rather on point H, the midpoint between E and F. This we will call the Offset Method of Mounting. The alternate method, which we will call the Centered Method, involves simply enlarging the secondary out to point G so that the distance from E to C and the distance from C to G are equal.

I will not attempt to discuss the relative merits of these two methods of mounting, but rather to explain, in each case, how to collimate the system.

Fig. 1 represents the absolute minimum size, in each case, of the secondary mirror for this particular system. Smaller secondaries will effectively reduce your on-axis aperture, resulting in a loss of illumination and a loss of resolving power at the center of the field. In practice, the apex of the light cone must be opened up to whatever full-aperture field you require at the focal plane, and not just brought to a point as I have done. Bear in mind that this will change the angle of the light cone, and thus will change the offset distance CH.

Incidentally, the minor axis of the offset secondary can be measured directly from the drawing (see fig. 1) by


A
G
PLANE OF
SECONDARY
MIRROR
F
C
H
FOCUSER
AXIS
x
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D
E
TUBE
AXIS
B

Fig. 1

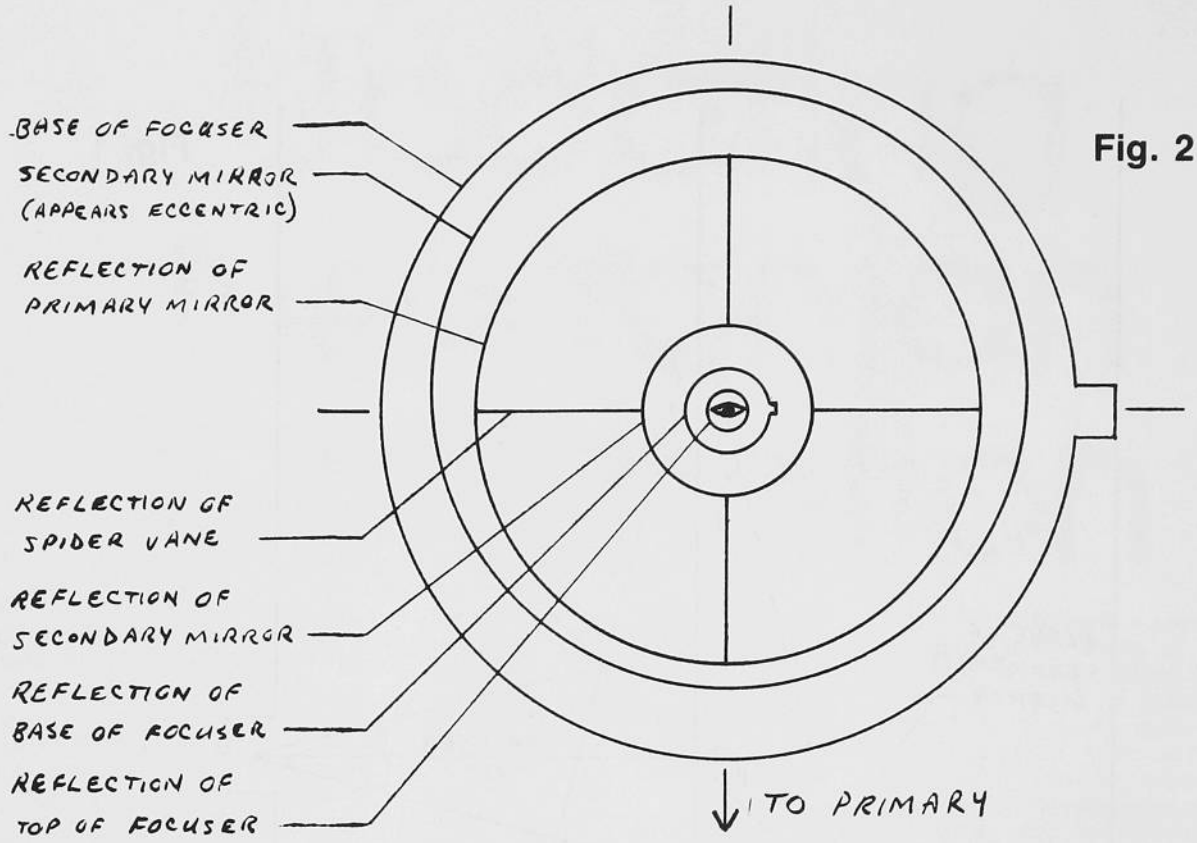

Fig. 2

Collimated Centered-Secondary System

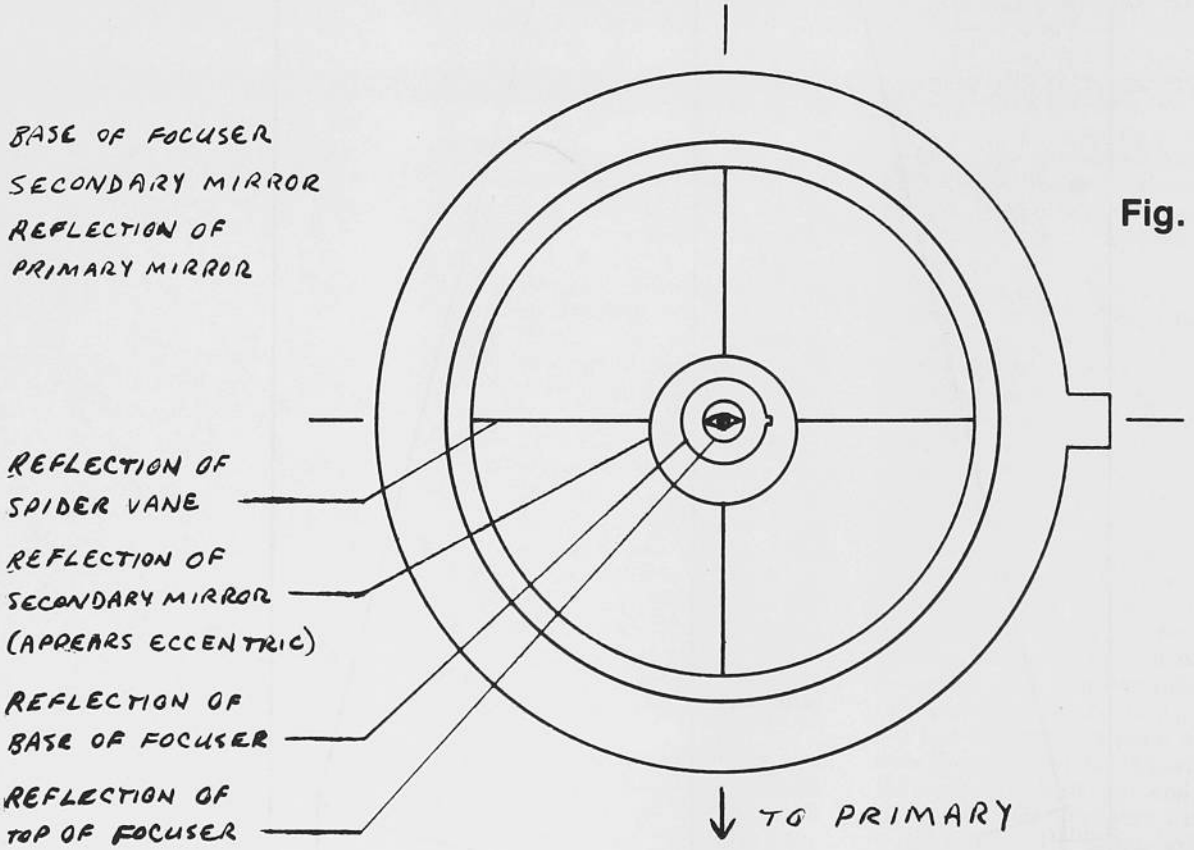

Fig. 3

Collimated Offset-Secondary System

drawing a line through point H (not point C) out to either side of the light cone. The minor axis of the centered secondary cannot be directly measured from the drawing, but can be arrived at by dividing the distance EG (the major axis) by the square root of two.

The optical illusion involved in collimation is not difficult to understand. The principle involved is one which is familiar to everyone, and which can be demonstrated by the following procedure. Find two objects of identical size, such as two coins, salt and pepper shakers, or simply your two hands. Place one object at arm's length and the other at about half that distance. The nearer object will obviously appear considerably larger. This illusion is so familiar that we tend to ignore it. This principle applies not only to two distinct objects, but equally well to two equal halves of the same object, providing that this object is tilted in such a manner that one side is nearer to the eye than the other, and that the object is fairly close to the eye. The Newtonian secondary mirror is such an object.

In the case of the centered secondary, by definition, equal amounts of the mirror face are on either side of the optical axis. But when we place the eye at point D (fig. 1), and look along the focuser (hence, optical) axis, we find that, because the upper end of the secondary is closer to the eye, the eye sees the upper end (CG) subtending a greater angle of view than the lower end (CE). As a result, the near half will appear larger, causing the secondary to appear to be too far up the main tube and so too far away from the primary mirror, even though we know it to be centered on the optical axis. In addition, point C, which remains centered in the field of view, will appear to be off-center on the secondary mirror.

In the case of the offset secondary, by virtue of angles x and y (fig. 1) being equal, length CF subtends the same angle as does length CE (the opposite ends of the offset secondary). The eye thus sees the mirror face centered about point C, even though point C is not centered between E and F, and even though the secondary is not centered on the optical axis. As a result of this optical illusion, it is not possible to make everything appear concentric in the focuser.

Figures 2 and 3 (exaggerated for clarity) indicate what should be seen in the focuser with proper collimation. With the centered secondary (fig. 2), collimation is accomplished by making everything that you see concentric except for the secondary mirror, which is affected by the optical illusion and whose apparent position can be ignored. The reflected image of the secondary is not affected by the optical illusion because of its apparent distance from the eye and the tiny angles involved.

With the offset secondary (fig. 3), collimation is accomplished by making everything that you see concentric except for the reflected image of the secondary mirror. The optical illusion in this case makes the secondary mirror appear centered, while its reflected image, too far away to be affected, appears as it really is: in other words, offset from center.

At this point, I recommend, particularly for fast systems, using collimating spots and a collimating tube, as described by Berry (TM#9) and Burnham and Berry (ASTRONOMY, January 1981).

These consist of a small spot placed on each mirror, and a tube of perhaps 15cm length which fits into the focuser and which has a small hole at the eye end and crosshairs at the other. These greatly facilitate the collimation procedure. The collimating tube assures us that we are looking precisely down the focuser (hence, optical) axis. I have seen a commercially-made centering device resembling an eyepiece, but with a pinhole in place of the optics. Without crosshairs, you must estimate the center of the inside of the base of the focuser by eye to locate the optical axis. The crosshair-type device is more accurate.

The purpose of the mirror spots is to locate the optical axis on each mirror. The spot on the primary mirror is obviously centered. The spot on the secondary mirror (refer to fig. 1) must, in every case, be at point C. In the case of the centered secondary, this will be the center of the mirror. In the case of the offset secondary, it will be necessary to offset the spot from the mirror's center (point H) up to point C. This offset distance can be calculated (see TM#9). To find the secondary offset, multiply the offset distance by the square root of 2. If this is not possible, measure from a scale drawing. (Please note that "Newtonian Notes" by Peter Francis gives an erroneous formula for calculating the offset.)

Concerning dot dimensions, Burnham and Berry recommend 5mm for the primary spot and 0.5mm for the secondary. Mine are somewhat larger, but I have a fairly large (44cm) telescope. The spots could be made quite large without impairing the function of the telescope, but they may be obstructive during collimation, so should be no larger than necessary to be seen clearly during the collimation procedure. The eye automatically focuses on the reflected images and must refocus to see the secondary spot, since it is real and not a reflected image. As such, it is a little hard to make out, particularly as it is seen on a fairly dark background. I suggest making the secondary spot white to contrast with the primary spot, and recommend using a flashlight to illuminate the face of the diagonal during collimation. The primary spot will appear dark regardless of its color (mine is white) unless the interior of your tube is brightly illuminated. The eye hole in the collimating tube simply centers the eye on the optical axis. Burnham and Berry recommend a 2mm diameter, but if this makes everything too dim, enlarge it somewhat.

This method of collimation is highly accurate, does not require a trained eye, and, once the spots are in place, is independent of the method of secondary mounting. It lends itself to systems with such features as non-elliptical secondaries, secondary supports which are not radially symmetrical, and other things which make concentricity hard to estimate.

I will now describe, in sequence, preliminary procedures which need doing for all collimation methods: eye collimation of the centered secondary system; eye collimation of the offset secondary system; and finally, collimation utilizing mirror spots and the collimating tube. The descriptions assume a vertical telescope tube.

General Procedures

1. If you are using the mirror spot system, the spots need to be put on before proceeding. Generally, ink, paint, or rub-down transfer dots are used. You will also need to construct the collimating tube. If you are collimating by eye alone, it is essential that the eye remain exactly centered in the top of the focuser during the collimation procedure. This can be accomplished by constantly checking the reflected image. Those things which are to be made concentric may be made so with respect to the inside of the base of the focuser, so it is essential that this be clearly visible. I recommend placing a piece of white paper inside the tube against the wall opposite the focuser for this purpose.

2. The bases of some commercial focusers have not been machined, and may not mount squarely on the tube. If you suspect that this is the case, correct before going further.

3. Rack the focuser all the way out. If you are using a collimating device, insert it into the focuser.

4. If you have a spider-type secondary

support, check that it is accurately centered on the tube axis.

5. If you have a tiltable secondary holder, either set it so that the mirror face is inclined 45° to the axis of the secondary holder, or else assume the angle to be correct, and remove whatever tilt, if any, it has previously been given. This is easier if you remove the holder from the telescope. If very little adjustment is necessary, this step may be skipped, as the angle will be more critically adjusted later.

6. If you removed the secondary holder, reinstall it so that the secondary mirror is facing the focuser and is approximately centered in the field of view of the focuser.

7. Rotate the secondary holder until the image of the primary mirror is centered side to side on the face of the secondary mirror.

8. The secondary holder should now appear centered side to side in the focuser tube. If it is not, then either there is still some sidewise tilt in the secondary holder or the spider is misaligned. This should be corrected and step 7 repeated.

9. Proceed to the specific procedure which applies to your system.

Eye Collimation with Centered Secondary

10. The primary mirror should be adjusted, if necessary, to bring the image of the secondary to the approximate center of the image of the primary. This does not need to be perfect, as we will return to it later.

11. You should be able to see the reflected image of the secondary mirror, and within that, the image of the base of the focuser slightly off center. Move the secondary holder along the tube axis (probably upward) until the image of the base of the focuser is centered on the image of the secondary holder.

12. At this point, ignoring the reflections in the primary mirror and ignoring the apparent position of the secondary mirror, the image of the primary mirror should appear concentric with the base of the focuser. If this is not the case, assuming that you have done everything correctly up to this point, then the secondary mirror is not set at 45°. Either the secondary holder has some residual tilt, or it is not cut accurately at 45°, or the secondary mirror is not mounted correctly in its holder, or the spider is incorrectly mounted. In any event, the necessary adjustments must be made to bring the primary mirror image concentric with the base of the focuser. Do not disturb the adjustment made in step 11.

13. Secondary mirror collimation should now be complete. Now adjust the primary mirror until the image of the secondary mirror is centered on the image of the primary. This completes the collimation procedure. If anything looks eccentric besides the secondary (which should look eccentric), then return to step 10 and repeat the procedure.

Eye Collimation with Offset Secondary

10. Move the secondary holder up and down the tube until the secondary mirror face appears concentric with the inside of the base of the focuser.

11. Rotate the secondary holder on its axis until the image of the primary mirror is centered side to side, ignoring the reflections in the primary mirror.

12. The image of the primary mirror should now be concentric with the face of the secondary mirror. If not, then the secondary mirror is not at a 45° angle. Either the secondary holder is tilted, or the spider is misaligned. Make whatever corrections are necessary to bring the image of the primary mirror to concentricity.

13. Secondary mirror collimation should now be complete. Since the reflected image of the secondary mirror is off-center, we cannot use it to collimate the primary. Adjust the primary mirror until the reflected image of either the spider vanes or the focuser is accurately centered on the image of the primary mirror. The collimation procedure is now complete. Everything should appear concentric except for the reflected image of the secondary mirror. If this is not the case, return to step 10 and repeat the procedure.

Collimation with Mirror Spots and Collimating Tube

10. Move the secondary holder up or down the tube axis until the secondary spot is centered on the crosshairs. If it is off to one side, it may be necessary to recheck the secondary holder for tilt, or to realign the spider.

11. Rotate the secondary holder until the image of the primary spot is centered on the secondary spot. If it will not center vertically, the secondary mirror angle is wrong, and you will either have to recheck the secondary holder once again for tilt, or realign the spider. This will complete secondary mirror collimation.

12. Adjust the primary mirror so that the reflected image of the collimating tube crosshairs (or eye-hole) is superimposed on the crosshairs. This completes the procedure. The two mirror spots, the crosshairs, and the image of the crosshairs (or eye-hole) should all be superimposed on each other. If not, return to step 10 and repeat the procedure.

If your Newtonian is slower than f/8, mirror spots are probably more trouble than they are worth. If it is faster than f/6 or larger than 20cm, you will probably not — unless you have a very talented eye — get adequate collimation without the mirror spots.

If your focal ratio falls somewhere in the middle, I suggest trying the eye method first. If you still have difficulty, try the collimating tube alone. (Use the spots as a last resort.) I recommend the collimating tube for any Newtonian, whether or not the spots are used. It will give you a better centering reference than the inside of the focuser.

In the "spots" method, the key factor is correct location of the spots. In the eye method, the key factor is an understanding of exactly what should be seen in the focuser.

A word of caution for those using the eye method: It is all too easy to confuse the objects with their reflected images in the collimation procedure. These must be kept straight.

I do not recommend star collimation as a sole method of collimating a Newtonian telescope. Star test collimation, as I understand it, involves adjusting only the primary mirror, but if a mistake has been made in collimation, it is typically an error in the alignment of the secondary mirror, and no amount of primary mirror adjustment will correct it. A telescope collimated by the dot method will be collimated as well as can be done.

Fast Newtonians are more than just "light buckets" and are capable, with proper adjustment, of a great deal more resolving power than they frequently display in the field. I hope that this article will help Newtonian owners obtain the full resolving power their telescope can deliver.

D. Eric Allen
1118 Swan Lake Rd.
Edmond, OK 7303

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Editor's Note: Those of you with 30, 36, 40 and 44cm Newtonian telescopes will obtain better performance by paying close attention to the details of collimation — I consider mirror spots and a collimated tube essential telescope accessories.

Letters

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Astronomy" Symposium held in Fairborn, Ohio. Over 70 amateur and professional TM and Microcomputer Nuts from the U.S., Canada, and Europe listened to some 30 papers heavy with the jargon of microcomputers, stepper motors, and such programming languages as FORTH. One paper was even read by a microcomputer! This is believed to be the first paper ever read at a Symposium by a microcomputer, and in a somewhat flat voice it pointed out that "Yuman" astronomers were difficult to communicate with over video monitors as they were always busy looking through eyepieces. The suggested cure was, of course, a talking control system.

For better or worse, microcomputers are now part of the TM scene. Of course TMs have always welcomed new technology and new approaches, and the scramble is on to explore the ins and outs of microcomputer telescope control. In the best TM tradition, some of the control approaches are downright cheap. A pretty good sized telescope in North Carolina was brought under microcomputer control for less than $100 and a Commodore computer. It is time to take your dime-store microcomputer, a few surplus stepper motors, some driver transistors, and mix them well and top with a dash of FORTH, BASIC, or your favorite seasoning.

You say you made Riverside, Stellafane, and the Texas Star Party, but didn't make Fairborn? You don't even know where Fairborn is? Shame on you! Fear not my good Yuman, it's all down in black and white — 30 detailed chapters — for a total of 270 gory pages (order from me, Willmann-Bell, or AstroMedia).

This time it's OK for you just to read about it, but next year you ought to come to "Microcomputers in Astronomy II." Circle July 12-14, 1984 on your calendar — you still have almost a year now to step out on steppers, go forth on FORTH, and figure out where Fairborn is.

Russell M. Genet
Fairborn Observatory
1247 Folk Road
Fairborn, OH 45324

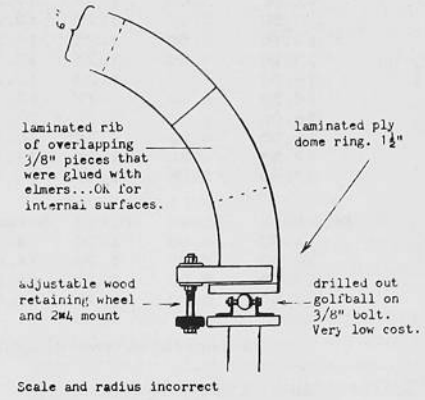
— Psst, it's near Dayton.

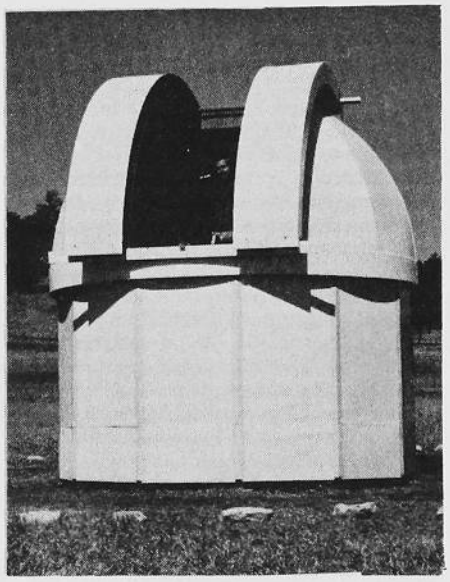
More on Domes

Dear Sir / In an effort to dispel some ideas put forth in TM#18 (no disrespect meant) about leaking masonite domes, my 12-foot dome has a masonite top and is very weather-resistant. It is now over 2 years old. The key to properly fastening a masonite section to a dome rib is a grey or brownish construction adhesive usually called Sta-Stuck or SS 4000. Any hardware store worth its salt should have it.

This adhesive is applied with an oversize caulking gun since the tube is much larger than the usual size tube, and it dries with the feel of hard rubber. The sections are glued, nailed, and remaining cracks are then filled (use the Sta-Stuck for this also) and smoothed with a thin, flexible piece of plastic cut from a margarine tub cover.

It's helpful to coat this plastic tool with silicone spray so that the dried adhesive can be peeled off. (Fingers could use this treatment, too.) I think it should be mentioned here (if it hasn't already been elsewhere), that it would seem entirely logical for bent masonite to warp, even to a





compound curve, after a period of time. That should minimize the chances of anything coming loose. When a dome using these adhesives is carefully made and bolted together, the result is a very rigid and leakproof unit. However, that doesn't mean you can skip all maintenance. Everything needs upkeep.

Here are a few more dome tips:

1. Make dome ribs from short arcs of ⅜" plywood laminated and nailed. A heavy duty stapler would be faster than nailing. Laminating smaller pieces allows better use of plywood.

2. Keep laminations out of the rain...obviously.

3. Buy your white glue for laminating in gallons, not quarts like I did.

4. Shutters are masonite over thin plywood with ¾" sides and ride on old grooved garage door wheels (small pulleys can be used, too). The angle iron rail is bolted to a 2x4. The shutters are opened by hand after removing a C-clamp inside. Slit width is about 39"; slit archs are 1½" thick.

5. The dome top turns on a multitude of siliconed golf balls set in a curved wooden track. Homemade retaining wheels turn on heavy and well-greased bolts. Golf balls do cause a little friction, so I have made the drawing to show an (untried) improvement which would use only about eight golf balls.

6. My building unbolts into 14 separate sections (use good quality caulk between sections as needed) and can be assembled by two people. My wife Shirley was a great help.

6a. A portable building will probably be taxed less than a permanent one.

7. Total cost of this building was under $400 because the floors, walls (¾") and ribs were made from free moving and storage crates in reasonable condition.

8. For all exterior painting use oil base paints.

9. Decide to build either a Cassegrain or a Newtonian, not a combination. Then plan your observatory's floor height accordingly. Climbing a ladder is a drag and I never got around to making the Cass focus operational.

Alan Raycraft
Box 301
Florissant, CO 80816

Kiln Technology

Dear Mr. Berry / This letter is a supplement to my note in TM#15 concerning glass fusion for large mirror blanks. After a year's on-and-off work, I have finally been able to construct my own 14¼" Pyrex mirror blank. The design of rib orientation is not like that used in the article in TM#14.

I found it too difficult to grind the compound curve on the ribs that were required to fit the slumped face plate. Instead, I decided to use a "spoked-wheel" design that radiates the ribs of unequal length from nearly the center of the faceplate toward the edge. At the outside rim of the faceplate, the ribs are 2⅞" apart. The spacing decreases and provides more support near the center.

The 14¼" has a ⅝" thick top plate, which allows an f/4 curve to be ground into it, a ½" bottom plate, supported on ⅜" ribs. Of course, for 16" and up, the foreplate must be sagged on a mold cut, or ground from firebrick; but the ribs can be readily cut or ground to the curve needed.

The thickness ratio for the 14¼" is 6:1, so it is 2¾" thick, thereby allowing conventional mounts, and minor supports, drives, etc. The internal rib supports are 1/16" to 3/32" less tall than the ribs to allow for compression during fusion, enabling good overall contact.

To aid fusion (and permit the use of standard kilns) the ribs and bottom plate were supported against sag by internal supports carved out of firebrick (the light brick used in kiln construction). These supports were carved in a "+" or T-cross section that allowed the heat to circulate around and through them. I also found out that a hole has to be cut through the bottom faceplate at least 2½" diameter to aid heat penetration.

Another critical point in using a standard enclosed kiln — unlike the one outlined in TM#14 — is to allow a period of at least 20-30 minutes soaking of the glass at 700 to 720°C to allow it to reach a uniform temperature before raising the temperature to the fusion

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point, and holding it there for at least 20 minutes. Each kiln has its own characteristics to which the operator has to become atuned.

Annealing, again, is critical and needs time.

In my own case, I ground the foreplate with #60 carbo using *lots* of pressure, and it has held up. The use of internal supports allows a greater margin of error for the novice, who can't afford many attempts at fusion. It also readily lends itself to larger sizes. My next project is a 28", which ought to be straightforward in execution.

For all the TMs who may not be able to build their own kilns, there are many in large cities at art studios. Ask, and they might let you experiment. Art colleges also offer courses on glass sagging and pottery finishing and have kilns. In my own case, the glass cost $175.00 Canadian (it would have been cheaper in the USA, of course!) and the use of studio kilns (even private kilns of potters) would bring the cost down very nicely.

Richard Rokosz
23 Lamont Ave.
Agincourt, Ontario
M1S 1A8 Canada

Downsizing Diagonals

Dear Richard / From the articles in TM about short f/ratio Newtonians and the advertisements by suppliers of sets of optics, I noticed that a lot of people have been making telescopes with diagonal mirrors far larger than they need to be. Old-fashioned books on telescope making warn that the diagonal mirror must be significantly larger than one that would just be needed to fit a light cone that comes to a point on the telescope's axis, but a little investigation shows that, in many cases, a diagonal that just fits the cone will work fine if we permit a slight loss of illumination at the extreme edge of the field of view.

The calculation of the diagonal size, given a certain loss of illumination (vignetting) at the field edge, is rather laborious, so Robert Pike and I wrote a computer program to do the job. The accompanying table shows the results for some common mirror diameters. I have chosen to make the calculations for a vignetting of 0.5 of a magnitude at the edge of a field of view 1.75 inches in diameter — that is the extreme corner of a 35mm camera frame or the edge of the field stop in a 2-inch diameter eyepiece with a very wide field of view. For each mirror diameter and f/ratio I have made two calculations: one for a mirror axis to focal plane distance (offset) of the mirror radius plus 4 inches and one for an offset of the radius plus six inches. The drop is the amount the diagonal must be moved away from the eyepiece so that the edge of the diagonal closest to the mirror receives all of the light cone, which is broader toward the mirror.

I recommend making the diagonal five or ten percent larger than the bare minimum figure in the table for two reasons:

1. It is very difficult to locate the diagonal on the center of the axis of the main mirror to a precision of better than +/−0.05 inch even if the telescope tube is stiff enough to keep it in position.

DIAGONAL MINOR AXIS CALCULATION

Units in Inches

Aperture	Speed	Field	Offset	Vig. mags.	Drop	Minor Axis
10.00	5.60	1.75	9.00	0.50	0.09	2.08
10.00	5.60	1.75	11.00	0.50	0.10	2.21
12.50	4.50	1.75	10.25	0.50	0.13	2.39
12.50	4.50	1.75	12.25	0.50	0.15	2.72*
12.50	5.00	1.75	10.25	0.50	0.11	2.29
12.50	5.00	1.75	12.25	0.50	0.12	2.48
13.10	4.50	1.75	10.55	0.50	0.13	2.43
13.10	4.50	1.75	12.55	0.50	0.15	2.79*
14.50	4.50	1.75	11.25	0.50	0.14	2.53
14.50	4.50	1.75	13.25	0.50	0.16	2.94*
16.00	4.50	1.75	12.00	0.50	0.15	2.67*
16.00	4.50	1.75	14.00	0.50	0.17	3.11*
17.50	4.50	1.75	12.75	0.50	0.16	2.83*
17.50	4.50	1.75	14.75	0.50	0.18	3.28*

Aperture	Speed	Field	Offset	Vig. mags.	Drop	Minor Axis
6.00	4.00	1.00	4.25	0.50	0.08	1.25
20.50	5.00	1.75	14.00	0.50	0.14	2.80*
20.50	5.00	1.75	16.00	0.50	0.16	3.20*
20.50	5.00	1.75	15.00	0.50	0.15	3.00*

* Indicates the diagonal fits an axial cone.

2. The quality of the extreme edge of diagonals is doubtful. Making the flat a trifle larger helps assure that the very center of the field has an image formed by light hitting high-quality surfaces.

Winnipeg amateur Bill Lawrence made up a 6" f/4 telescope with a bare minimum diagonal only 1.25 inches in diameter. Bill was able to achieve this by making a low-profile focuser using the focusing barrel of a damaged 50mm camera lense to accommodate an offset of just 4.25 inches. This telescope performs dramatically better than it did when it had a 2.5-inch diagonal. Star images at the center of the field are crisper, showing a diffraction image with more energy in the central spot. Planets exhibit much better contrast and detail; in fact, at medium to high powers, it's like looking through an excellent 6-inch f/8.There is no detectable loss of quality due to a bad diagonal edge.

Accepting an insignificant loss of light at the edge of the field and using a small diagonal improve more than the image quality of the telescope. Large flats and spiders are expensive, and even going one size smaller in a large Dobsonian means a significant saving.

For the formulae used in the computer program see *The Size of the Newtonian Diagonal* by William T. Peters and Robert Pike, *S&T*, March 1977. I will be happy to send anyone requesting it a Pascal listing of a program using equations slightly improved from those in the article. If TM readers would like a calculation of the diagonal size for a system they are planning, they should send me the aperture, f/ratio, field, permissable vignetting, and offsets. Forty cents to cover postage and a self-addressed envelope (sorry, but American stamps don't work in Canada) would be appreciated.

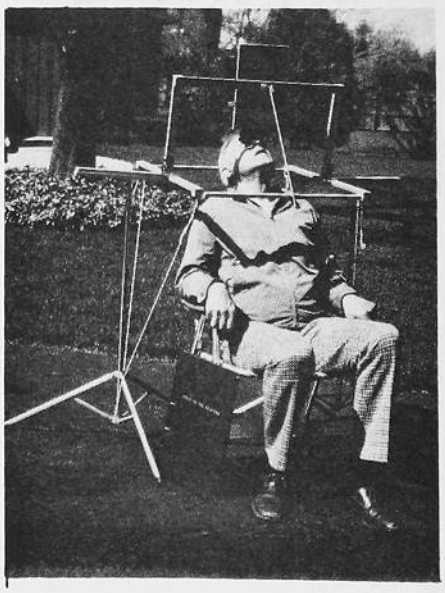
William T. Peters
c/o The Manitoba Planetarium
190 Rupert Avenue
Winnipeg, Canada R3B ON2

Binocular Mount

Dear Mr. Berry / I thought your readers might be interested in my simple, inexpensive mount for binoculars. The main frame is 26" square made of ½" x ½" scrap lumber (it was cut from a wider piece at the lumber yard). The declination frame is 14" x 26" and hinged to the main frame at the center of the main frame sides. The projections from each side are 12" long double thickness. Several holes are drilled through the bottom layer to accept the extension bar of the photoflood light stands. Several holes are provided in case the observer desires to spread the stands farther apart.

Note the ropes from each corner of the main frame to the bottom of the stands. When tightened, the set-up is very rigid. The binocular mounting board rotates on a bolt at the center of the declination frame. A small dowel bar is nailed to the lower edge of this board to support the binoculars which are held tightly to the board with a web strap. The eyepieces extend over the dowel, while the rear of the binocular body rests against the dowel.

The declination adjustment is made with the ¼ x 20 threaded rod. The upper end is bent into a hook U which is passed through



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a screw eye in the bottom of the front of the declination frame. The lower end of the ¼" rod is passed through the body of a turn buckle from which the front eye bolt is removed. The rear eye bolt clamps the rod in the desired position.

I have found that the hinge pins should be aligned with the ears of the observer for maximum comfort at all angles of declination. In the photo, you see me in the most uncomfortable position — observing beyond the zenith.

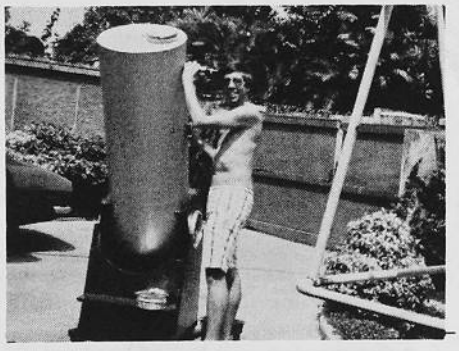
The only disadvantage to this design is that practical movement of the binoculars is restricted to about 20° in azimuth which may curb those who want to sweep the skies. Most often I find my observations are confined by choice to one area at a time anyhow, so this has not been a problem.

H.J. Stelzer
1223 Ashland Avenue
River Forest, IL 60305

Fan Mail

Dear Mr. Berry / You are a hero and I want you to know it. Your initiatives are great, and your hiring "lone fighter" Dave Eicher proves it again. You do a very great service for the real, active amateur and I assure you I will be a lifelong subscriber to *Astronomy, Telescope Making,* and *Deep Sky.*

I have been a telescope maker since I was 9 years old (now 41), and my latest endeavor is the 17.5-inch Dobsonian in the picture included. I built it in two months time. I was



down with hepatitis Dec. '81-Jan. '82 and that gave me the chance to build the scope. The preliminaries, of course, were literally years of writing to various companies. I ordered very early in 1981 and w-a-i-t-e-d — but everything arrived here safely in December of 1981. Well, I had the time!

This scope is very fine for deep sky viewing and a good performer when stopped down to some 8" on the Moon and planets but not up to the definition of my 6-inch f/8 Jaegers refractor (another saga was the contacts I had with Jaegers). Of my 8-inch Celestron, I can only say it is a big disappointment and a very poor performer when put next to my 6-inch Jaegers refractor — built early 1981 in some spare weekends. It also performs poorly when compared with my 10-inch and 12.5-inch double reflector with Meade mounting — efficient, business-like people — Coulter optics, and Novak hardware which I also built Dec'81/Jan'82. It was a creative time. . . .

You advised me in correspondence in 1981 as to the reliability of American suppliers; I am still grateful to you for that. I had a disaster with Cave where I paid over $3,000 for a 12.5-inch reflector: the money went down the drain when they went out of business.

This year in Indonesia will be exciting: I am "man in the field" for Amateur Astronomers of New Jersey, who will come some 70 strong next June. Are you coming? As to my nationality, I am a Dutchman having worked some 20 years overseas (Africa, Japan, Indonesia) for a large Dutch Trading/Industrial Company, so I have not only seen the skies but also our own world.

With kindest personal regards,

R.G. Rijmer
P.O. Box 485
Jakarta, Indonesia

— I would have been most delighted to meet you while I was in Indonesia myself, but could not find the letter (which I remembered and knew I had somewhere) with your address on it. The letter turned up again late in the process of assembling this issue of TM.

Aperture-Mania

Dear Sir / I'd like to contribute a few words about the current state of aperture-mania, specifically on just how big an aperture is practical or even desirable. A few simple equations define the characteristics of deep-sky telescopes. It turns out that the eyepiece, the observer's eye pupil opening, and the field desired completely define what the minimum magnification and aperture are for any telescope.

Let's consider an example using one of the largest eyepieces available today: a 38mm Erfle with a field stop 2.1" in diameter. Here's how it works out. Given real field, L, (in degrees) and field stop diameter, d, we find the focal length, F:

$$F = 57.3 \times d/L$$
$$F = 57.3 \times 2.1/1$$
$$F = 120.3$$

Next, magnification (where e is the eyepiece focal length):

$$M = 25.4 \times F/e$$
$$M = 25.4 \times 120.3/38$$
$$M = 80.4$$

Then aperture, D, giving exit pupil P:

$$D = M \times P/25.4$$
$$D = 7 \times 80.3/25.4$$
$$D = 22.2$$

Finally, the F# of Resulting Telescope

$$F\# = F/D$$
$$F\# = 120.3/22.2$$
$$F\# = 5.4$$

A table can be constructed for any eyepiece. Short-focus eyepieces drive the f# downward, and small apparent fields reduce the maximum usable aperture.

An interesting consequence of this analysis is that extreme f/ratios (f/5 and lower) are not required except to shorten the telescope; a weak Barlow is needed for low f/ratio telescopes to obtain the maximum usable aperture.

Now, just what is the "largest usable aperture"? If you know your maximum eyepupil diameter and then select the maximum real field, the answer is given in the table you've constructed. A larger aperture is then not possible unless you can find an eyepiece having a bigger field and/or shorter focal length than the 38mm x 2.1" Erfle.

Note that a reasonable selection might be a 0.5° field of view with a 6mm exit pupil, resulting in a 38" aperture f/6.3 instrument. Such an instrument would allow you to see just about anything worth looking at!

Andy Saulietis
2010 Silverpines Rd.
Houston, TX 77062

Injustice to Mirotar

Dear Mr. Berry / The article on the performance of astrocameras in TM#18 contains a very serious flaw: the instruments compared in it have different focal ratios, ranging from f/1.25 to f/8, yet their performance is compared at an equal scale in millimeters rather than degrees off-axis!

The image quality at the edge of a 1" field of Astrostar could only be meaningful when compared to the image quality at the edge of a 6.25" field of Sigler's f/8 Maksutov.

In addition, the authors misrepresent the actual designs in use. For example, the Heliotar II was shown to be rather poor at f/3. The same design was used by Zeiss in Germany for the successful Mirotar lenses of up to 7" in diameter and working at f/5.6.

I have seen photographs made with this objective, and I strongly urge you to write to Zeiss and convince yourself of this. In fact, the Mirotar lenses were especially designed for astrophotography — but obviously couldn't give satisfactory images at f/3. Very few lenses do!

Mladen Vranjican, M.D.
63-141 Alderton St.
Rego Park, NY 1137

— I would hope that most readers realized the intent of the article was not to discuss the angular resolving ability of a variety of optical systems, but to investigate their ability to form useful images on photographic films roughly 6cm across.

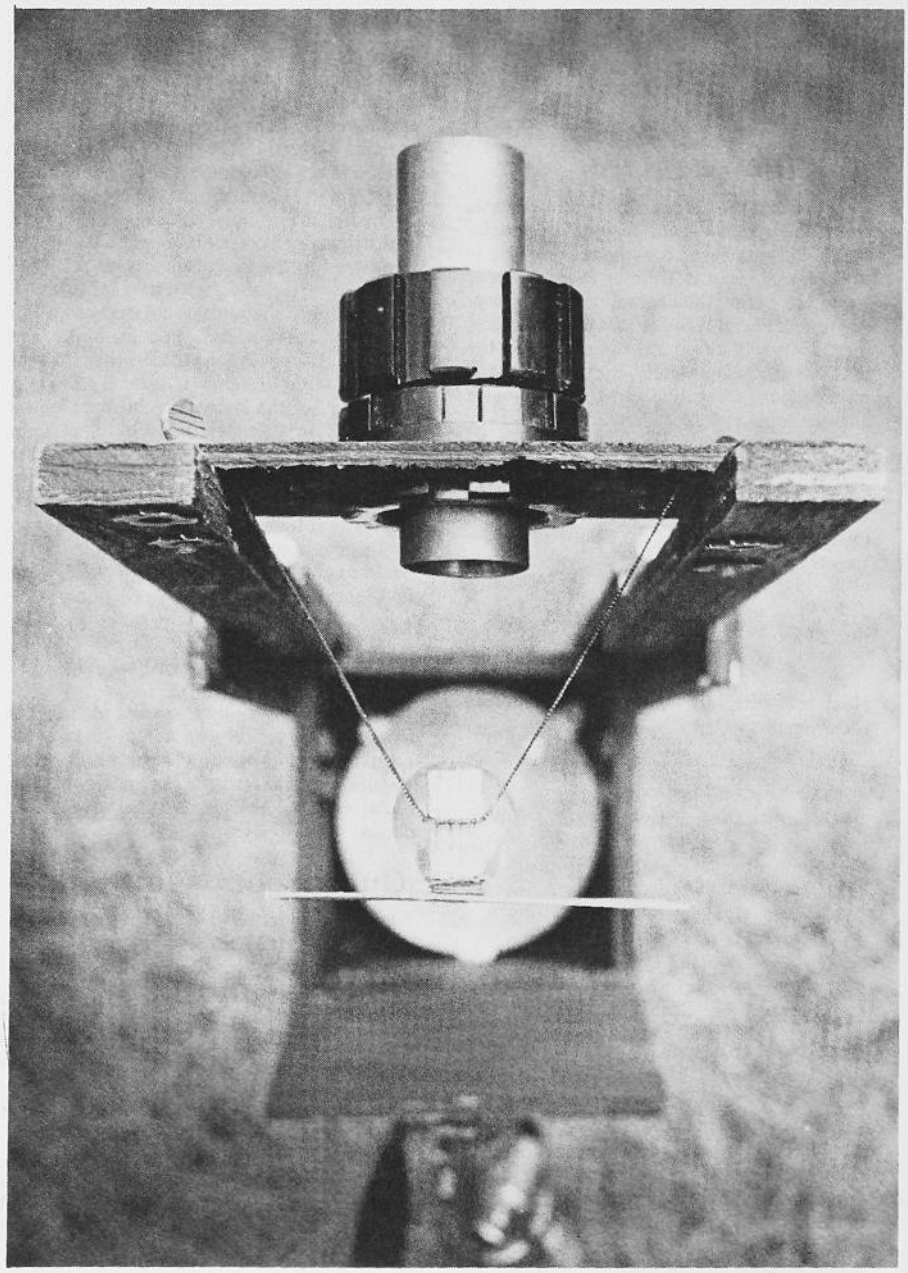
Quick Spots, Wot?

Dear Mr. Berry / The "H'tanU' Curve" article in TM#21 presented a very useful, proven method for determining residual aberrations and image quality of optical systems. However, John Gregory who wrote the article, and Robert Cox who commented on it, portrayed alternative methods such as spot diagrams, in particular, as prohibitively expensive, time-consuming and difficult for an amateur. This is not really true.

With all respect to their opinions, sophisticated optical analysis is very much within reach of an amateur's time and budget. To illustrate this, I enclose a set of

45►

An Ultra-Portable 6″ Reflector

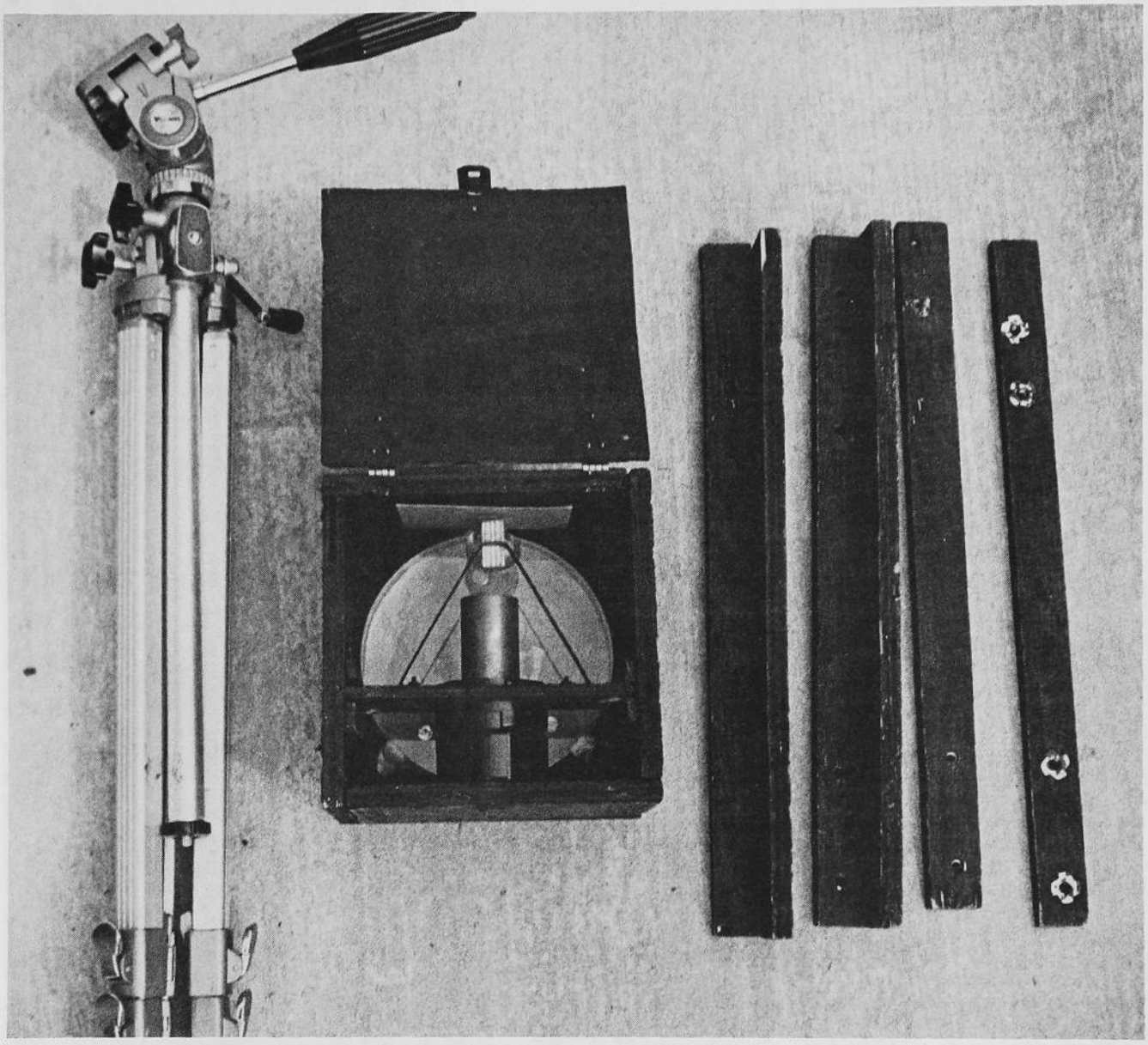


I observe under the world's darkest skies. But because of space limitations aboard my military duty station, the aircraft carrier *USS America* (CV-66), I was forced to come up with a telescope — in a hurry — to take advantage of those skies. I couldn't take just any telescope — one had to be designed for the purpose. When I thought about it, these restrictions presented themselves:

- *Optics* — the aperture, powers to be used, field of view, and focal ratio had to be right to insure I could use it on a ship at sea.
- *Speed* — the ship was leaving the United States on a seven-month overseas deployment in six months, which meant starting the mirror right away.
- *Size* — I needed to be able to store this scope in my largest personal locker, a space 20 inches deep, 15 inches wide, and 7 inches high.
- *Weight* — the telescope had to be light because I have to carry the entire scope and observing aids eleven stories up, in one trip, to my observing station.
- *Construction* — it had to be simple; I wanted to build it myself using hand tools available on the ship.
- *Quick Tear-down* — certain situations force me to be at certain places within five to ten minutes at any time of the day or night. These include general quarters, fires, and man-overboard drills.

Having used a 4.25″ f/4 RFT on board *America* in 1981 and 1982, I was convinced a 6″ f/5.6 Newtonian reflector with a 2.8° field of view would do okay on board the 80,000 ton vessel. The ship rocks anywhere from 0° to 10° depending on the weather and wind conditions.

I started the mirror in June of 1982 and finished it, only slightly under-corrected, in August, just prior to the ship's leaving on a three month "North



Atlantic" cruise. I did not receive the mirror back from being aluminized until early October. It chased the ship from Norfolk to Scotland to England to Spain, and finally caught up with us in the Mediterranean Sea off the coast of Beirut, Lebanon. Due to ship's operations and clouds, I did final testing there to prove to myself that it would work. Three weeks later, in the Atlantic and Caribbean Seas, I tried the mirror, hastily mounted on a heavy plank atop a bulky photo tripod.

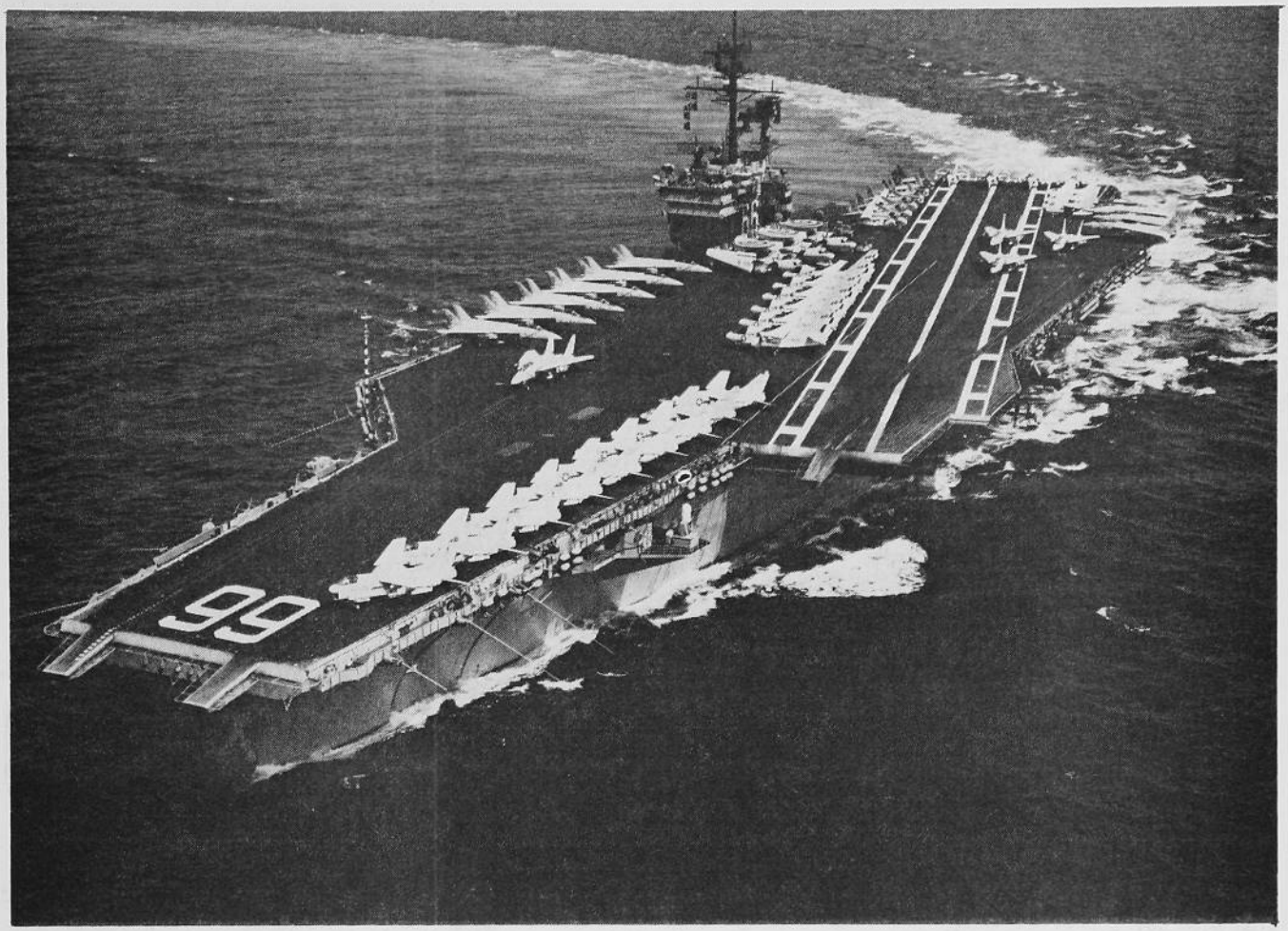
Upon return to the United States in mid-November '82, I had just one month to finish the scope before we left for the Indian Ocean and those southern skies! A visit to my hometown, Columbus, Ohio, allowed me to see Tom Burns and Dick Suiter's "Boppian" 17.5" telescope, written up in TM#19. Ideas churned out, and by early December I had settled the basic design. It took one day for cutting wood, and one more for putting it together, so it was done just in time for December 8 departure.

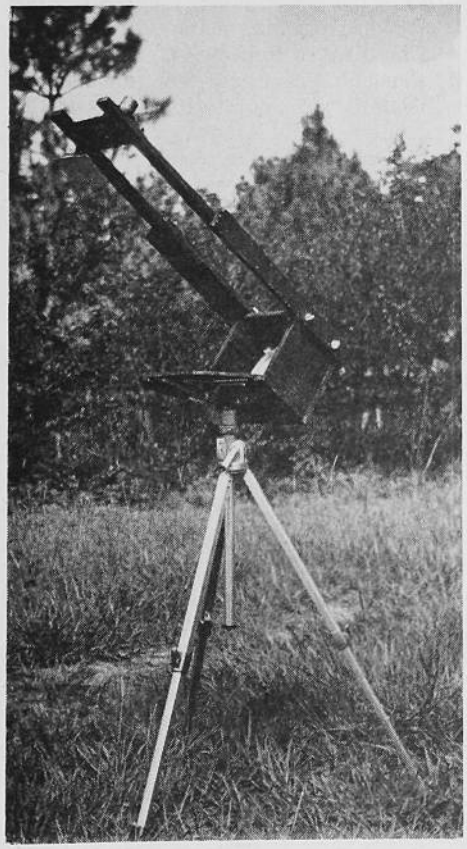
Most of the scope is made of ½" plywood. The mirror box is 7.5" square and 6.5" high. The deep box with a hinged lid and six scraps of wood allows the ¼" plywood focus board to slide in and stop right above the mirror. This box now securely holds all of the optics for transportation. The two struts are cut in half so that I end up with four 17" long sticks. The bottom struts are two 1"x17" lengths of ½" plywood, glued and nailed together into an "L" shape. They're held to the mirror box by two ¼x20 thumbscrews threaded into T-nuts countersunk into the mirror box.

The upper struts are single pieces of ½" plywood and are bolted to the bottom strut using the same method used with the bottom struts. The focus board is ¼" plywood held onto the top struts with two ¼x20 thumbscrews and T-nuts, one screw per strut — upper corner one side, lower corner on the other side. The diagonal holder is a bent hacksaw blade similar to the Burns/Suiter design, but with the ends folding inward instead of outward.

The focuser is a "stuffing tube" (used where wires run into a fuse box) filed out from 1.125" to slide-fit with a piece of 1.25" I.D. brass tubing, with a setscrew threaded into the stuffing tube's plastic to hold the eyepiece. The entire scope attaches to a mid-size photo tripod via one of two ¼x20 Tee-nuts in the mirror box. This allows the eyepiece to be on the top or on the side.

The scope weighs about seven pounds, and fits — along with the tripod





(with head screwed off) — into a green bag that is nineteen inches long. This bag also carries a box of eyepieces, *Handbook of Constellations* (Vehrenburg), a complete set of *Astro-Cards*, and my variable star charts.

Since all bolts are thumbscrews threading into T-nuts, and all are ¼x20 thread, no tools, color coding, or tool boxes are needed. Bolts are put into a plastic bag and carefully snuggled into a corner of the mirror box against the mirror. The hinged door on the box opens away from the struts and acts as a partial light baffle. The door is shut prior to disassembly so that bolts don't fall on the mirror. The entire set-up time is five to ten minutes. Tear-down takes the same amount of time, but putting the tripod and charts into the bag and carrying the assembled scope takes only a couple of minutes.

On land, vibration limits this scope to low and mid powers unless you are very patient, but this is not usually a problem at sea. As could be expected, vibrations and rocking motions of the ship limit me to low powers most of the time.

This scope has seen much action, including over 50,000 miles of travel and southern skies. Even though the scope looks beat-up and shaky, over thirty-five nights of use in the last six months and an impressive record of 12.5 and 13th magnitude galaxies seen, prove that it works very well.

This design will work for both the beginner with few tools and little money, to the owners of 17″ optics that have old "out-apertured" 4″ to 8″ optics hidden in a closet. This design is very compact and is perfect for plane and car trips in which even a Boppian 17″ wouldn't fit.

There is no reason that you have to use the materials that I used. The best thing to do is think about it for several days, being very careful to look around and see what you have available for a "low-tech" scope similar to this. Hacksaw blades and stuffing tubes are easily obtainable. Old aluminum siding would work, as would the classic bathroom sink drainer. The most important thing is to keep it simple. The less there is to a scope, the less there is to break just when you are setting up under the darkest skies you've ever seen!

PH2 Robert Bunge
Photolab/OPS
USS America (CV-66)
FPO NY, NY 09531

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On Slitless Testers

The following arrived at our TM editorial offices (actually, a small table in the corner of my office) as a letter, and continues a discussion between Dick Suiter and myself. Slitless testers — or perhaps more correctly, single-knife testers — have been around for a long time; I built my first in the early 70s. When I had mentioned to Dick that my forthcoming book included a slitless tester with a moveable stage sliding on Teflon vees, he looked astonished. We were so busy at AstroFest last year (with clear skies and all!) that we didn't get a chance to compare notes. Dick then sent the following article to me as a letter; I feel there is more than enough new good stuff in it to publish it for everybody's benefit.

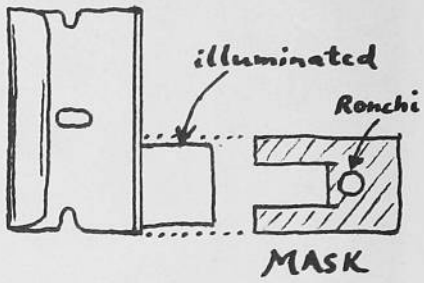
Incidentally, Dick asks me to be sure to remind everybody that the longitudinal aberration of a paraboloid in a moving source tester is $r^2/2R$, or twice its value in the stationary source testers in common use.

For those new to the slitless Foucault tester, the idea is simple. In conducting the Foucault test, if you illuminate one end of a single knife-edge from behind, the mirror will form a flipped and inverted image of the knife and light source. If you arrange the test so that image falls on the knife, the knife and the real image of the knife formed by the mirror form a slit — so you supposedly don't need a slit source for the tester.

There are two main advantages. First, the image of the knife is always exactly parallel to the image of itself providing the knife-edge is straight. This eliminates the whole business of "squaring-on" the knife-edge. Second, because the image is not a skinny slit, but a large, bright blob, the test is very easy to set up.

The major disadvantage is that there is a fair amount of extraneous light from the bright blob, which makes seeing the mirror shadows difficult. I simply added a half-length knife-edge (Suiter calls the second knife-edge a mask) which could be flipped into place after getting the system aligned — this cuts the glare greatly.

One additional point should be mentioned: artifacts in the Foucault image occur because the eye is so far behind the knife-edge, so I use a 2x or 3x telescope to image the slit back into the plane of the eye's pupil. Most of the floaters, eyelashes, specks, and swirly things go away. Additionally, the telescope provides a bigger and sharply focused view of the shadow patterns on the mirror, which is especially helpful in judging zones with a Couder test mask.



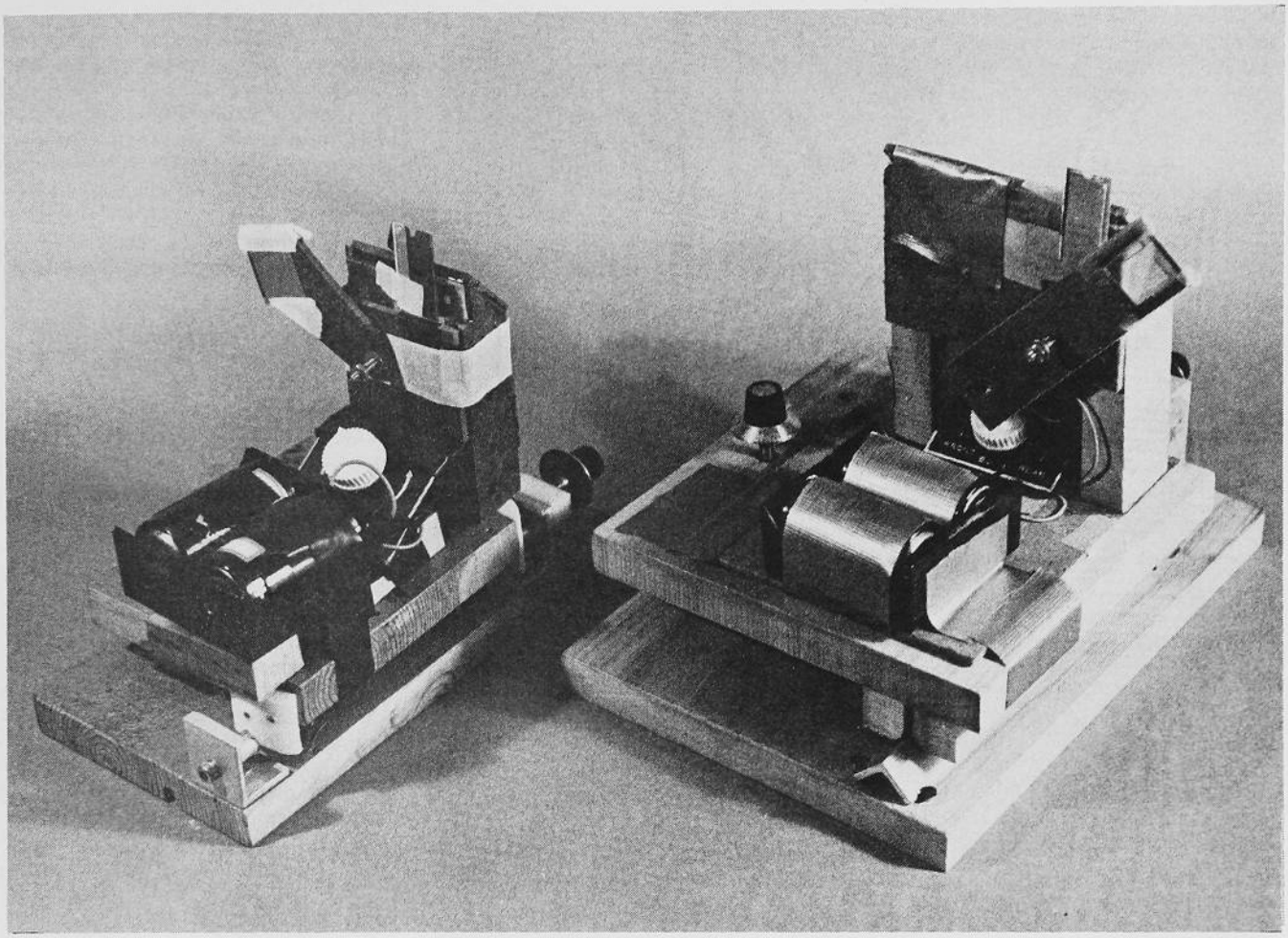
Dear Richard / I wanted to talk to you at Astrofest about our simultaneous development of the simplified Teflon riding slitless Foucault tester, but I never got around to it. I had intended to write TM an article about my tester, but your saying you were including a description of a slitless tester in your book made an article seem like a duplication of effort. So I thought the best thing to do would be to write you about my particular tester and let you glean any peculiarities of my device and discuss some (I believe) inaccuracies in the published literature about this type of tester.

In reference to your observation that the other side of the "slit" must be covered by a mask: when you first told me about this over the phone, I tried it and found that it really helped. Although I have successfully figured mirrors without this mask, it is nice not having to squint through glare to see the surface of the mirror.

I looked up the old reference to this glare effect in *S&T*, September 1970; there I found a statement that I believe to be in error. In the little addendum to another article, the statement is made that the glare is caused by the uncovered side of the slit "scattering forward and illuminating the mirror." This seemed to be wrong because the Foucault test is best done in a slightly illuminated room, and that slight amount of light is much greater than can be supplied by the tester.

I believe a much simpler explanation can account for the glare: the excess light is simply excess light coming past the knife edge from a surface that does not null. On a surface that does null (i.e., a sphere), it makes no difference whether or not you cover the other side of the slit with a mask — the excess light is imaged on the back of the knife. I've verified this with my testers when testing a sphere. I covered one tester and left the other wide open and found little difference between them.

When testing an aberrated system (such as a paraboloid at the center of the curvature), we get tons of light stuffed in our eyes by the fact that the knife is not imaged in the same plane by the whole mirror — it depends on the zone. Looking at the center zone of a paraboloid, unusual amounts of light "leak" past the knife from the edge zone. This light is limited by the other side of the slit in a normal Foucault tester.



We can use this information to approximate the maximum width of the slit for effective glare reduction. The reason that it's an approximation is that it all depends where the knife is and how much aberration is present.

$$\text{slit width} = \frac{\text{longitudinal aberration}}{(4 \times \text{infinity focal ratio})}$$

For a paraboloid at the center of curvature, we find the following inequalities:

$$\text{slit width} = r^2 / 4F$$

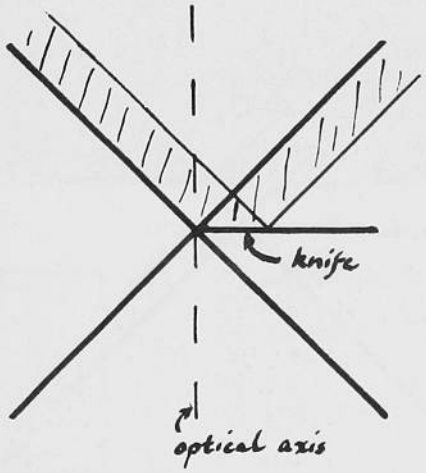
$$= (D^2/16f) / 4F$$

$$= (D/16F) / 4F$$

$$= D / 64F^2$$

with r = half the diameter of the mirror
R = distance from mirror to COC
D = diameter of mirror
f = infinity focal length of mirror
F = infinity focal ratio F = f/D.

For example, an 8" f/6 mirror results in a maximum slit of .0035 inch. So, for an

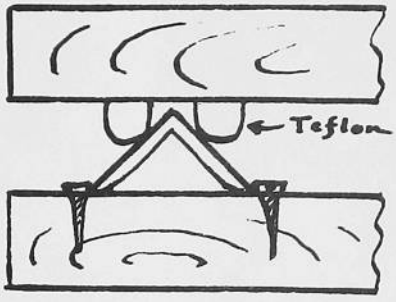


slitless Foucault tester testing a sphere at center of curvature (COC). All zones have same COC.

shaded region is depicting width of "slit" during imaging

8" f/6 mirror, the slit width must be less than .004 inch if it is to cut any glare.

It seems as though I have proved the opposite of the effect observed when testing spheres. The slit width calculates out to be zero when we know it can be left wide open. What we have shown is that to improve the contrast of a nulled image, we have to decrease the slit width to zero. The nulled slit image suffers little from contrast problems already, and we can do little to improve it.



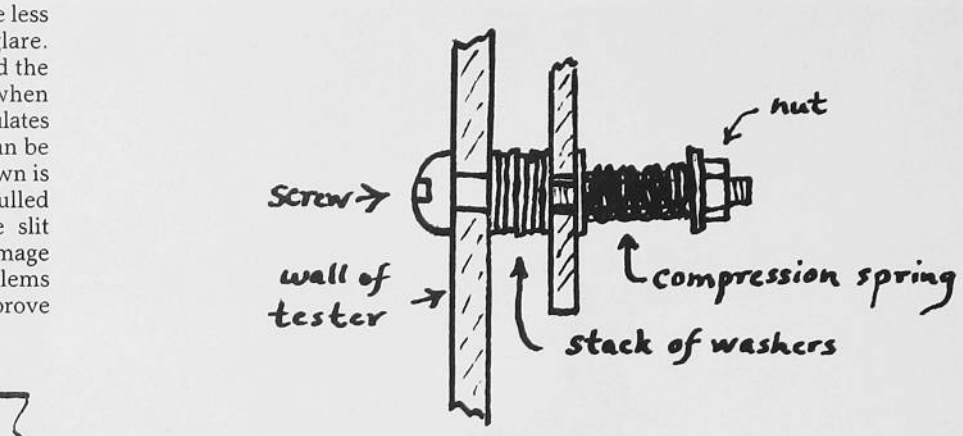
An interesting feature of the above argument is that once we move out a few times farther than $r^2/4F$, we can once again be assured that excess light dumps on the knife. This allows us to punch "Ronchi holes" or "finder holes" in the mask. You can see this in my drawing of my mask. (I slip the tabs behind the knife, making a tiny slit between them.) The Ronchi hole allows me to back the knife way out and swing in a Ronchi ruling covering both the hole and my eye for an automatically aligned Ronchi test. I can also pump more light through the hole than I can pump through the slit, which makes finding the image easier. I need not worry about my Ronchi hole when I do the classical Foucault test, because all of the light getting through this hole, including aberrations, hits the rear side of the knife.

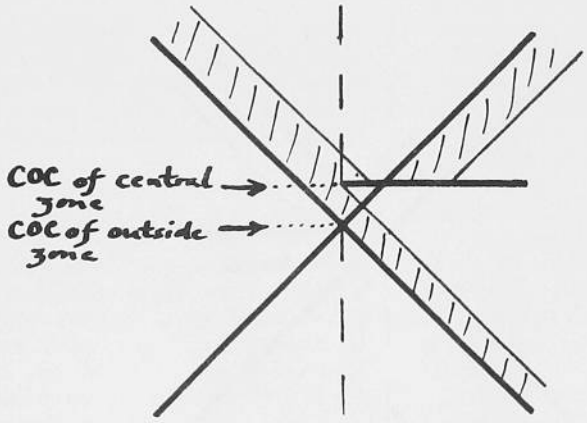
Other interesting features of my tester include:

1) The sliding rail is a piece of the same extruded aluminum angle that I said I liked in my TM#19 article. It is placed face down and held by screws on the outside. Bearing surfaces on the bottom of the platform consist of four pieces of Teflon. [I used ¼-inch hardware store steel rod — RB.]

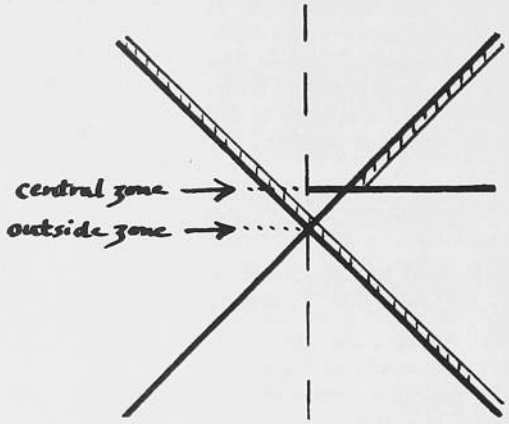
2) "Swing out" appliances like my Ronchi screen are held on a device constructed from simple washers and a compression spring. [On mine, the entire Foucault slit unit is replaced with a slip-on Ronchi unit.]

3) I have dispensed with the use of a prism and cannot imagine why it was ever used. I just use a 45° angle covered with aluminum foil. Immediately behind the knife I use a diffuser consisting of several layers of Scotch





slitless Foucault tester sitting at COC of central zone while testing paraboloid (outside zone shown). Note excess light "leaking" past knife from outside zone



normal "slitted" tester testing paraboloid as above. Note light is limited by slit width. This can also be the situation with a masked slitless tester.

tape (this is very important). [Another similarity between the Suiter and Berry testers — except I used buffed aluminum to reflect and diffuse.]

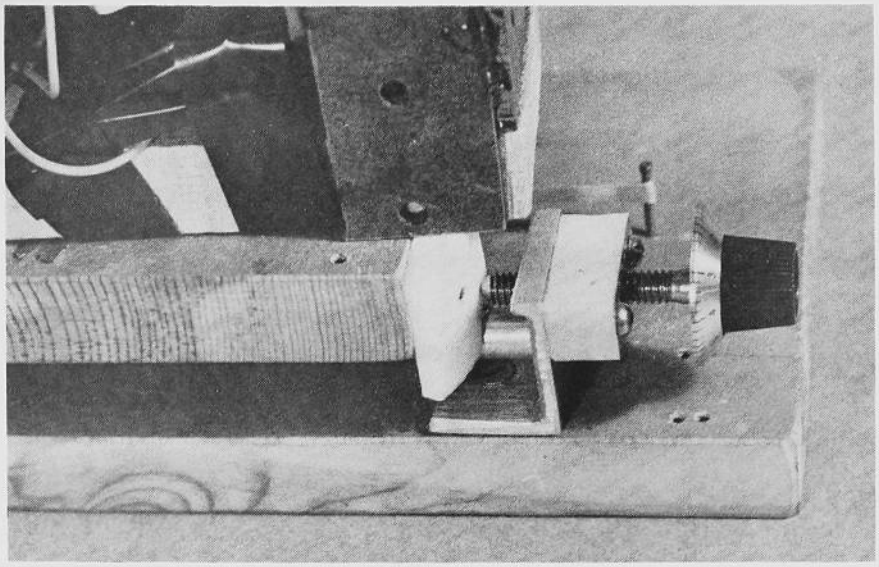
(This reminds me of the Suiter/Burns philosophy of telescope making: If you can't tape it, glue it. If you can't glue it, nail it. If you can't nail it, screw it! Contrast this to the Porter/Ingalls philosophy!)

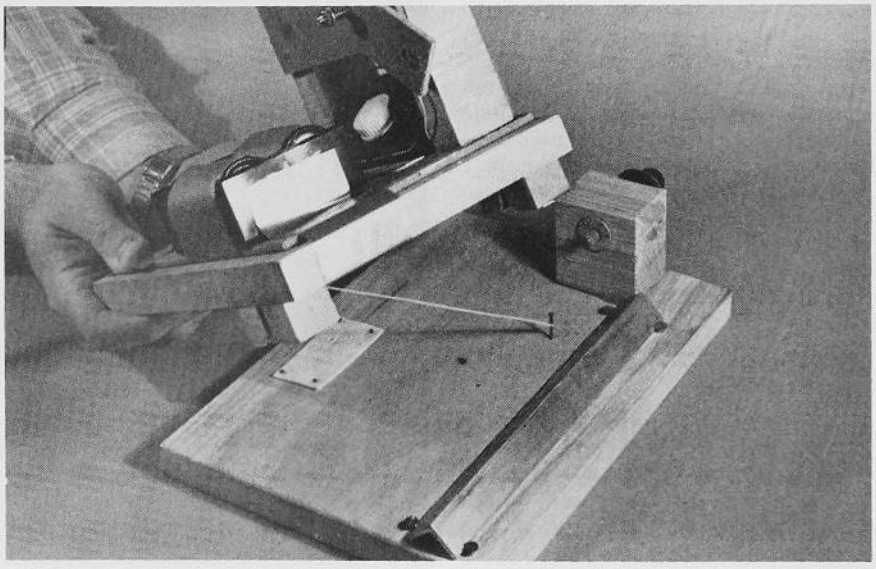
4) The screw that is used as a micrometer is a ¼"-20 threaded bolt. It bears against a piece of Teflon. I advise making the bolt end sharp, but not too sharp. You have to avoid the large periodic error of a flat bolt bearing against nonuniform Teflon, yet you don't want to make the bolt so sharp it digs holes in the Teflon and has sudden errors when it breaks out of them. This is perfect. [I tried to file a hemisphere on the tip of mine. Chucking the bolt in a hand drill, and running it against fine emery paper smoothed it nicely.]

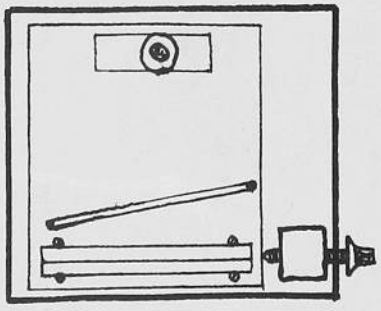
5) The bolt can sit in a T-nut (one of my testers is built like this), but the method I like much better is to tap a screw hole into a piece of nylon or Teflon. This is better because these materials don't accept drills or tapping tools very well and they stretch when being tapped. When the tap is taken away, they relax a tiny amount, getting a little bit smaller. When you thread the bolt into them, you get a tight, "oozy" feeling that only comes with metals when you have tapped them perfectly and then lubricated them. It has absolutely no backlash or wiggle. Don't get a piece of nylon or Teflon much thinner than ⅜" or much thicker than ½", though. (Don't worry about the relaxation effect making the threads unreliable micrometers. Distance is measured by the SCREW, not the threads.) [I used two T-nuts 2" apart, and opposed, to grip the screw tightly.]

6) A rubber band is sufficient to hold the platform against the screw. I drive a nail partway into both boards and string the rubber band between them. I find that the best angle, however, is not parallel to the rail, but cocked in toward the rail at the far end. [I used little springs from the hardware store, also angled slightly.]

7) So far, I have accounted for five degrees of freedom. The other one is simultaneously an adjustment screw and a bearing, like the one appearing in Texereau. But unlike Texereau, I used







a sheet of Teflon as the bearing surface instead of a piece of glass. The funny thing about this is that this screw rocks in its T-nut quite a bit, but I haven't seen the slightest hindrance to my doing the test. It doesn't seem to matter. [Same here.]

8) I use a simple circuit consisting of a #222 condenser bulb (a penlight bulb), a socket to hold it, an SPST switch, two "D" cells, and a potentiometer to dim the light and lengthen the life of the bulb. Unfortunately, Radio Shack no longer carries 30 to 50 ohm pots such as were needed in this circuit. A good alternative is an automobile stereo balancer, which is a pot even though it isn't called one. Radio Shack has several models of this item — get the cheapest. Wire it from the middle to either outside terminal just like ordinary pots. The advantage of operating your light source on battery power is that you don't have to be near a wall socket to use it.

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Guiding for Astrophotography

Introduction. Four years ago, I constructed an automatic photoelectric guider for the Dynamax-8 I then owned. The guider was mounted on a 60mm guidescope and could guide on a 5.5 magnitude star; with an off-axis system on the main telescope, it could guide with a 9.1 magnitude star. The tracking accuracy of this system was about 1 micrometer, although the construction of the tracker is relatively simple and costs less than $50 in new parts — given some access to secondhand hardware. This system is still operative, but I have recently built an updated version with higher-quality components, an even simpler design, and a 10-fold increase in simplicity. Since I am not an electronics engineer, the design can't be complicated!

Sky Motion. How long can you expose stars before a photograph becomes smeared by sky motion? The starry sky turns once every 24 hours — which is 15 degrees per hour or 15 arc-seconds per second of time. Suppose your camera is aimed at some star near the celestial equator and the shutter is opened. The star moves and so does its image on film, causing an exposed trail. Naturally, this trail will turn out to be longer with longer exposure and greater focal length. As a matter of fact, the maximum allowable exposure time to obtain trails so short that we may call them "pointlike" is surprisingly short: only 2 seconds for a 50mm lens and 0.1 second for a one meter focal length is the limit. Apart from the question of whether trails are or are not beautiful, such short exposures are far too short to catch faint stars. The only way to get sharp, untrailed pictures is by guiding.

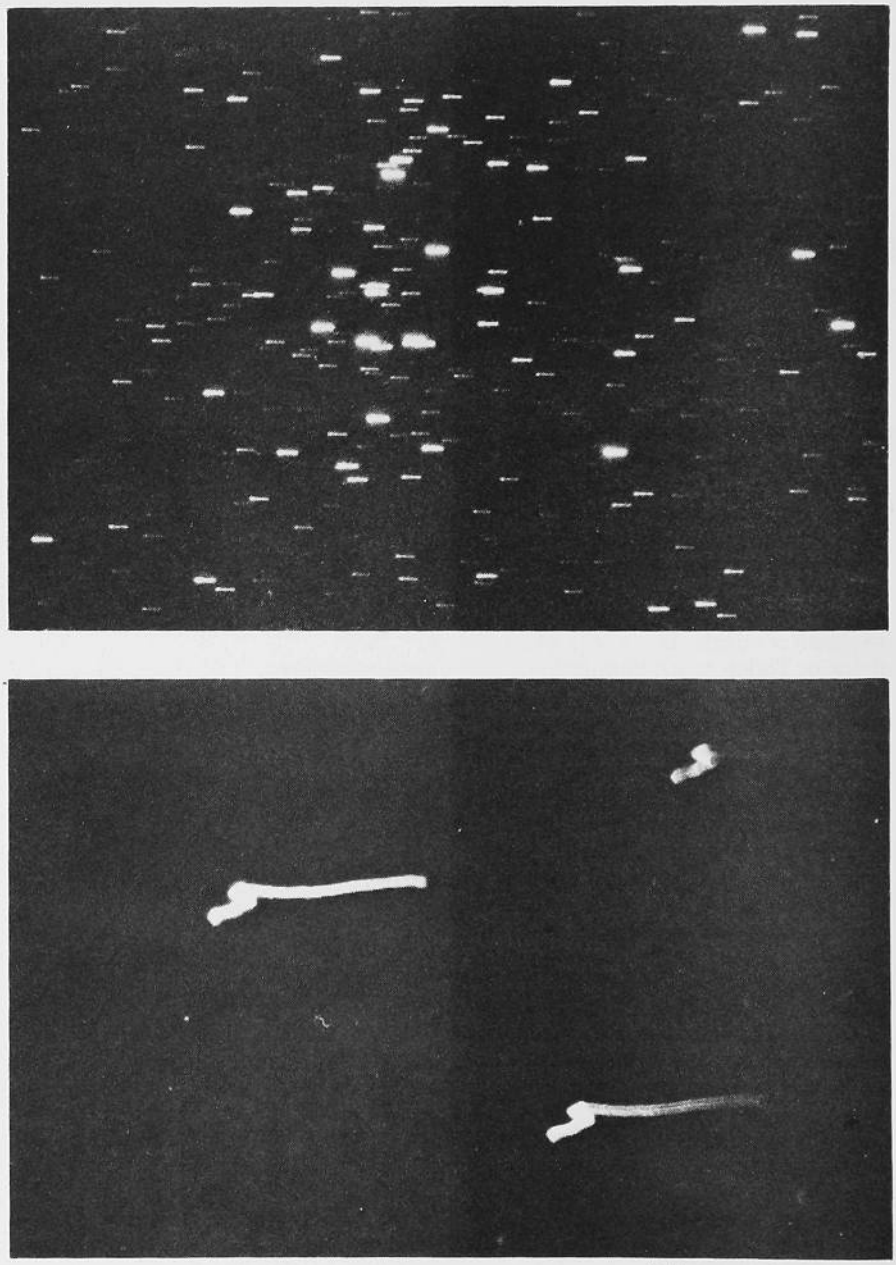


Figure 1
Guiding errors can occur in one direction (a) or in both right ascension and declination (b), producing snakelike or multiple star images.

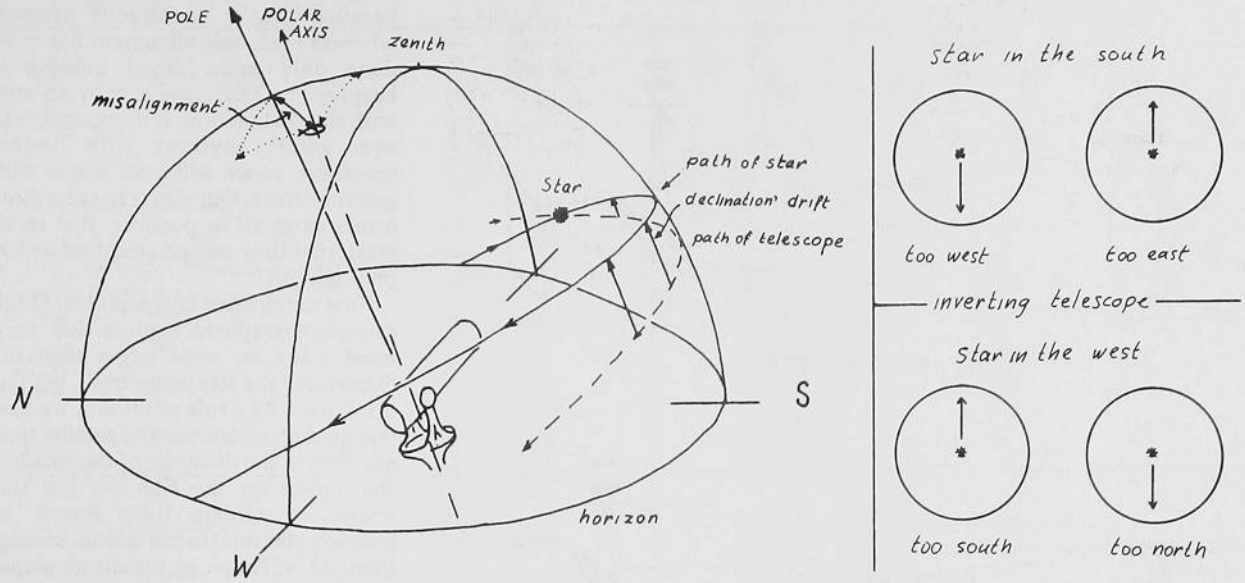


Figure 2
Misalignment of the polar axis causes a star to drift in declination in some regions of the sky, even if the RA motor runs correctly.

The solution is to give the camera the same angular speed as the stars so that the telescope accurately tracks the path of the stars along the sky. In this way, the camera always points to the same position in the sky and a steady image results. To achieve this guiding motion, we have to place the camera on a moving platform.

Equatorial Mounts. The sky seems to rotate around an axis through the celestial poles, and your camera must do the same. Therefore, the mount which holds the camera should contain an axis parallel to the Earth's axis and be driven at an accurately determined rate. This axis is called the polar axis and serves to compensate for the east-to-west motion of the sky. A platform with a polar axis is called an *equatorial mount* and comes in many forms. You also need a second axis to adjust the camera to an object's height above the equator. This is the declination axis, and it is perpendicular to the polar axis. The construction of such an equatorial mount is a different story, but sturdiness is essential.

Most of the commercial mounts available to amateurs are far too sloppy; as a general rule, good stuff is expensive (and not the other way around!). Building your own is the usual solution — but even a perfect mount is no guarantee for perfectly guided astrophotos. In photography, everything has to be done much more precisely than with visual observation, and every flaw is unforgivingly recorded.

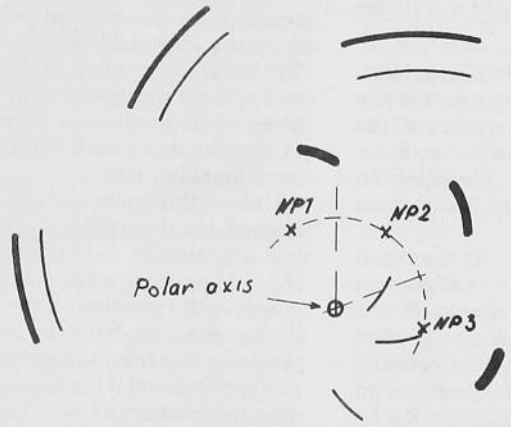
Murphy's law is very much in the game of astrophotography. The equatorial mount has two axes, so guiding errors manifest themselves in two directions (see fig. 1). There are two remedies for these errors: good guiding and good aligning of the polar axis. In the next section, I will tell some more about this, and finally, say something about a homemade photoelectric autoguider.

Aligning the Polar Axis. For easy guiding, an accurately adjusted polar axis is a must. I use three methods to align the polar axis, which I shall describe in order of increasing accuracy.

First, the polar axis can be roughly adjusted by simply moving the telescope parallel to the polar axis and aiming the finderscope to the celestial pole. This can be done very easily with a special polar finder which can be set to the pole star. Aligning the optical axis to the polar shaft is not too difficult. If an object (e.g., the pole star) is viewed through the telescope at low magnification, and the telescope is revolved around the polar axis, the position of the object should stay in the middle of the field of view. With one of the popular Schmidt-Cassegrain telescopes, this alignment is even simpler. The nearly-flat Schmidt plate in the front of these telescopes reflects an image of the pole star and of other objects like treetops, etc. When the telescope is turned around, this reflected image will describe small circles unless the polar and optical axes are precisely parallel.

The second method is the well-known trick of declination drift. The telescope is aimed at a bright star around the meridian and near the equator at high magnification. The direction of drift is observed and the mount readjusted

Figure 3
A schematic triple star trail photograph of the north celestial pole. It is possible to accurately measure the position of the polar axis by exposing the pole in three telescope positions on one negative. The polar axis' position can easily be derived from the positions of the three north poles (NP 1-3) on the plate.



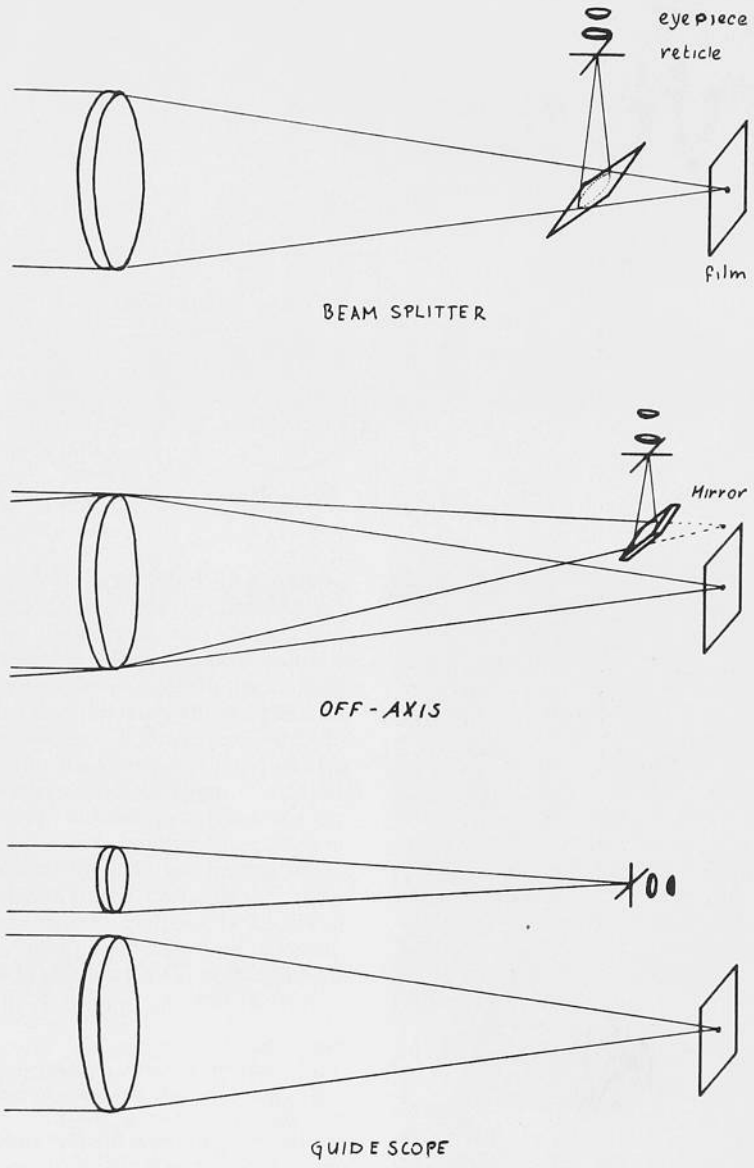


Figure 4
Principles of the three most important guiding systems. With all three systems, a guide star is kept on the center of the reticle of a guiding eyepiece.

accordingly, as indicated in fig. 2. Next, the telescope is put on a star not too low above the east or west horizon and the same adjustment is made, until no observable drift remains. The precision of this method is usually limited to a tenth of a degree.

Much more accurate is the third method I developed for the alignment of my flat-field camera mount. It is a photographic method based on the fact that stars revolve around the celestial pole, and the telescope revolves around the polar axis — and that both can be recorded on one plate. The telescope is roughly aimed at the pole, and an exposure of 30 minutes is made with right ascension drive switched off. On the negative, pieces of circular trails will be recorded, arcs of polar star trails centered on the celestial pole. During exposure, the telescope is twice turned 30° in right ascension, so that each star makes three pieces of 10 minutes' trail. The negative will show three systems of circular trails, each centered on the corresponding pole.

Unless the polar axis is perfectly aligned, the three poles on the negative will not coincide, but instead will lie on the circumference of a circle whose center is the position of the polar axis of the telescope. Now the deviation of the polar axis from the right position is easily calculated if the time and date of the exposures are known. I achieved an alignment accuracy of better than 0.01° in one such correction.

Good guiding is more difficult because it is a continuous process, whereas polar axis alignment has to be done only once. Good guiding is keeping the telescope exactly in step with sidereal motion. It is impossible to ever adjust anything with perfect exactness, so we will have to live with guiding errors. Our aim is to keep these errors as small as possible, that is, so small that they escape attention on the photographs.

How much error is acceptable? Often astrophotographers assume that they must make no error larger than the diameter of the star image itself, but this is not true. As a rule of thumb, we find that guiding errors must be smaller than one fifth of the diameter of the smallest star image on the film for the star images to remain truly round. In practice, star images are seldom smaller than 20 microns in the focal plane, which means guiding errors should be smaller than 4 microns — and preferably only 2 or 3 microns at the focal plane.

Guiding errors often seen in amateur astrophotography consist of multiple star images — overlapping well-guided images. This type of error typically is the result of mechanical flexure between guidescope and main telescope. With off-axis guiders, these errors cannot occur.

Practical Guiding. Fancy this: You have been taking photographs all night under perfect conditions and your eyes ache from staring in the eyepiece. Expecting nothing but fantastic pictures, you develop your film only to discover that it is decorated with snakelike curves instead of pointlike stars. How come? For good guiding, it is necessary to keep the camera perfectly directed toward the object. Therefore, the telescope must be equatorially mounted and the polar axis slowly turned at a very uniform rate. You need some form of gearing to do this. The very simple forms with flexible, hand-held axes are well known, but they are not sufficiently accurate for photography. Instead, a motor-driven clock is necessary to drive the telescope.

In many mounts, a synchronous motor is employed, running in step with the 60 Hz line frequency. Although this frequency is fairly constant, guiding errors still occur. They are caused mainly by small periodic errors in the driving gear train, so that the telescope runs erratically while the motor runs okay. Surprisingly, 10% deviations are no exception. The solution is simple: make the motor run erratically in such a way that the telescope runs okay. A synchronous motor's speed can be controlled by varying the frequency of the voltage supply. The power source is then usually a variable frequency

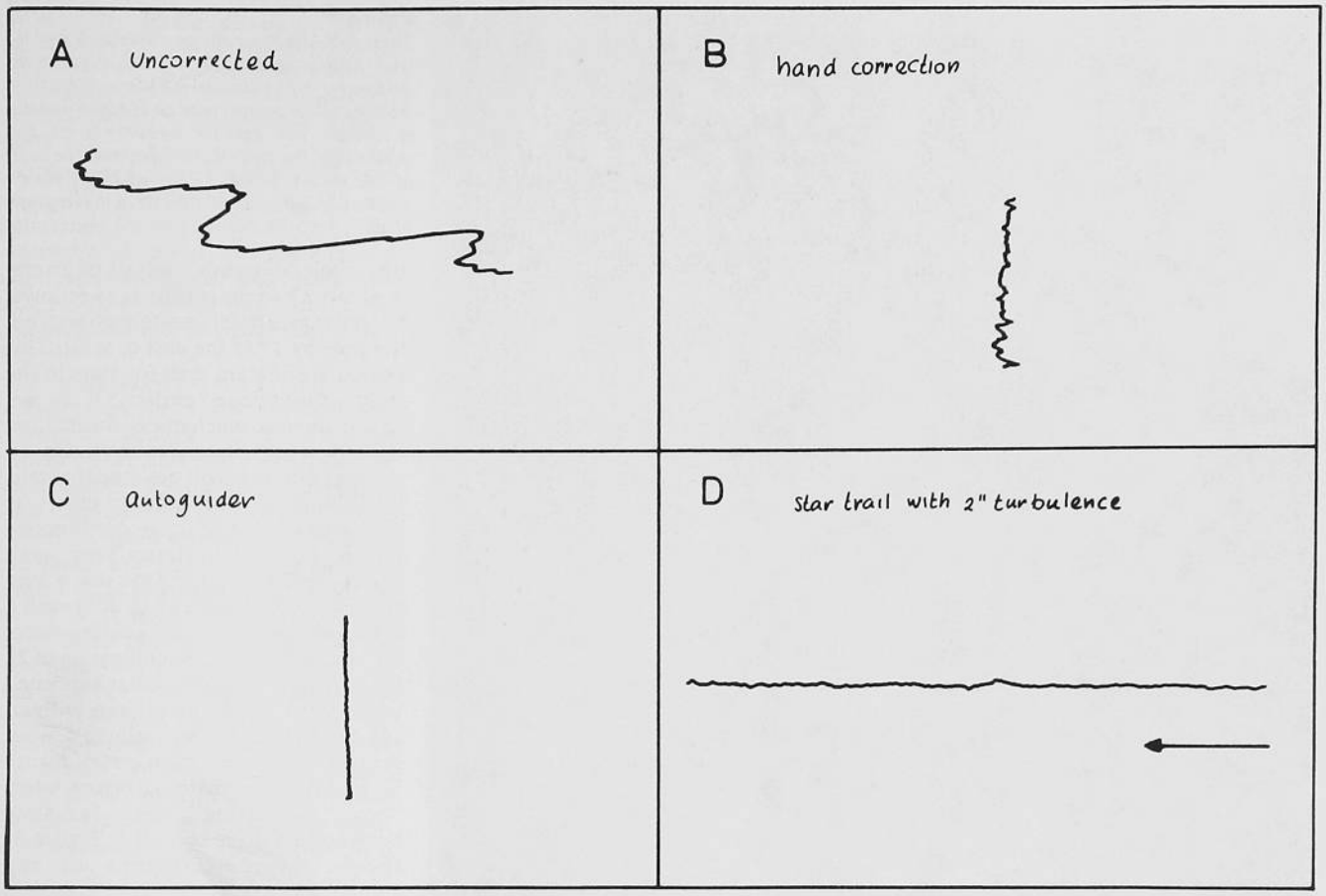


Figure 5
Declination trails of a star of ten minutes exposure, showing the guiding errors. a) Uncorrected declination trail; these are the gear train errors to be corrected for. b) The effect of hand correction with fast/slow buttons. c) Performance of autoguider described in the text. d) Star trail at high magnification with RA drive off. Atmospheric turbulence distorts the trail.

electronic oscillator operating from a car battery. Guiding is achieved by projecting a star image on a reticle (or two crossed wires) and taking care all the time that the star doesn't shift from the center. The image of the field being photographed falls on the film and is obviously not available for guiding — but there are ways around this.

Three Guiding Methods. The off-axis method uses a guiding star outside the field of the photograph, but still in the field of the telescope. Before the light cone from the objective comes to focus, the beam is deflected by a small mirror or prism, projecting the star on a guiding reticle. This structure is usually built in a special camera ring with a guiding eyepiece holder on its side and can be very compact. Off-axis guiders are commercially available, but it is easy to build your own.

Off-axis guiding can be considered highly dependable because photographic optics and guiding optics are the same, and no mechanical flexures are likely to ruin the photograph. Off-axis guiding has one drawback: many times only very faint stars are available in the field and sometimes the guide star is on the "wrong side" of the main object, forcing the observer to hang upside down under his telescope.

The guiding telescope removes the problem of chronic shortage of well-placed guide stars because it is adjustable, independent of the main scope. Thus, bright stars can be fixed and the objective diameter can be small to cut costs. If the guidescope can be offset 5° in all directions, you are virtually certain of finding a guide star brighter than about magnitude five. The problem here is that the construction has to be very rigid indeed; the slightest shift or flexure between the two telescopes clearly ruins your photograph. 0.001mm of flexure really isn't a lot! A well-constructed guiding telescope, however, offers the most comfortable guiding, in my opinion, although undoubtedly the off-axis method is, in principle, more elegant. To use a photoelectric autoguider, bright guiding stars are necessary.

The third possibility for guiding is a beam splitter, which splits the incident light in amplitude — in other words, image brightness is decreased. Its most important application will therefore be lunar and planetary photography, where light conditions are not as severe as with stars and nebulae. A feature of this method is that guiding eyepiece and film have the same seeing conditions. My guiding telescope works in this manner, but a photodetector is used in place of the film.

In all three cases, we are trying to keep a star image steady by locking into another star image on a reticle. Strictly speaking, we do not even need two crossed wires, as one vertical wire should suffice if the polar axis is properly aligned. As a reticle for visual inspection, I use 0.01mm tungsten wires illuminated from the side by red LEDs; 0.01mm is just a little less than my guidescope's Airy disk. Seeing effects make a star image flicker off the wire on either side. By keeping these sides equally bright, a guiding precision of 2 microns can be reached. This is so accurate that only a small guidescope can do the job, although guiding errors in the guidescope are multiplied on the photograph by the ratio in focal lengths.

Measuring Guiding Errors. If an astrophotograph was badly guided, there can be no doubt that something went wrong. But there are no clues to what went wrong and when! In other words, it is necessary to introduce a

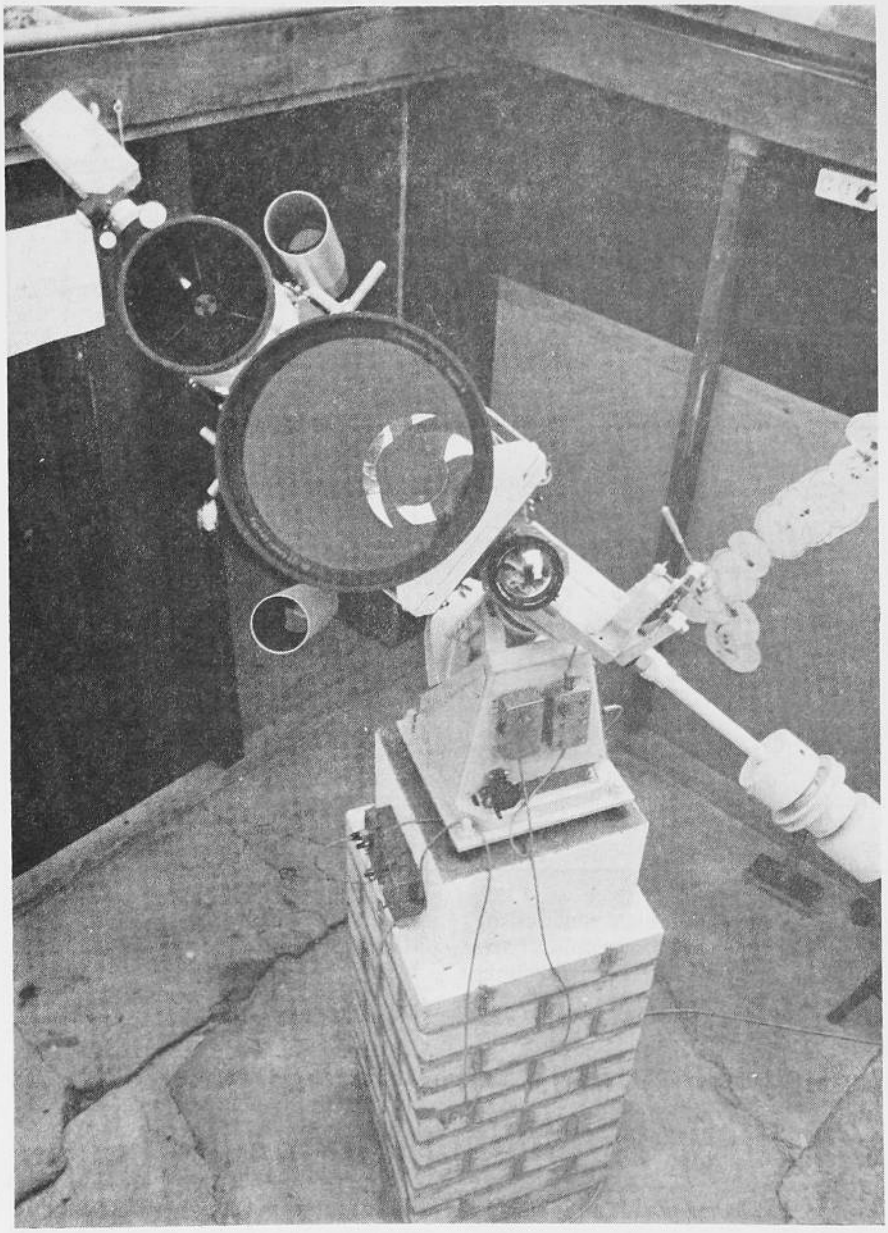
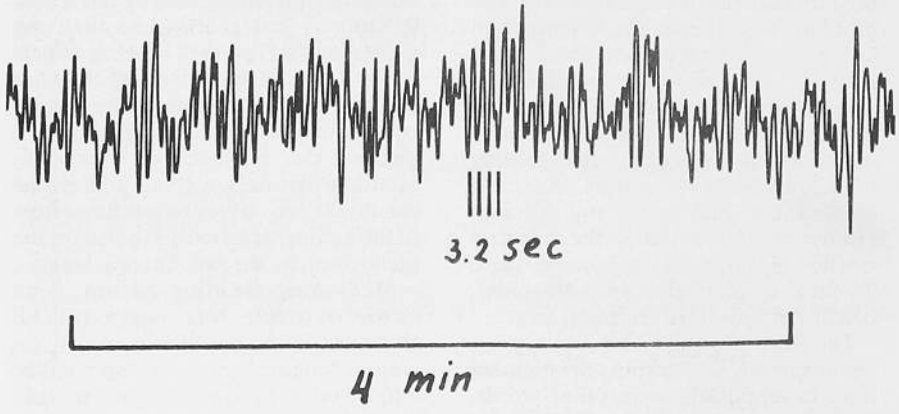


Figure 6
The autoguider in service on a 190mm Schmidt-type astrocamera with 115mm Newtonian guidescope, both with 50mm finders. At bottom, a 58mm f/0.85 camera with an H-alpha camera is visible. The detector housing is on the guidescope, the control amplifier is on the base of the mount, power supply and DC motor control are in the case at the side of the concrete block.

time scale to permit analysis of errors. A nice way of doing this is as follows: the polar axis is deliberately offset from the pole by 1° to the east or west. This causes declination drift for stars in the south as mentioned earlier. Of course, if you have a mechanical declination drive, you must keep it running. On the photograph, you will get straight trails in declination with guiding errors as deviations, just like on an oscilloscope screen. In order to detect very small guiding errors, you should use a long effective focal length of 10.20m with a 0.5m guidescope, so that guiding errors are recorded with a magnification of 20 times. Figure 5a shows what happened when I just let the motor run without any correction for ten minutes; what you see are the gear train errors. Figure 5b shows the remaining errors when "hand correcting" with fast/slow buttons on a drive corrector. Figure 5c shows the performance of my autoguider.

Using the same setup, we can measure the seeing disturbance. Bad seeing causes a star trail which is not perfectly straight, but somewhat shaky and sinuous. Figure 5d is such a trail, taken straight overhead at reasonable seeing conditions (2 arc-second stellar image motions). As you see, these vibrations are not vanishingly small, and they show up not only as enlarged star images, but also as guiding errors!

Automatic Guiding System. Hand guiding can clearly be done with great



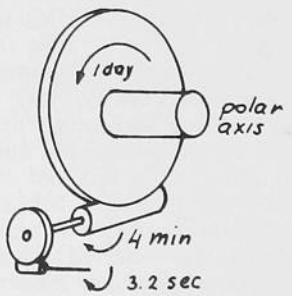


Figure 7
A pen recorder noted the variations in motor speed, as controlled by the autoguider. The gear train is shown schematically; periodic errors of both gears can be recognized in this four-minute recording. It helps to view the recording at a small angle.

Figure 8
Automatically guided picture of the S Monocerotis region, reproduced here at an 18x enlargement from the negative. Exposure was 60 minutes on hypered 2415 with an RG2 red filter in a 760mm f/4 optimized Slevogt Schmidt camera.

precision, but is very tiring with bad gears like mine and cannot be maintained for any length of time. The observer's attention will inescapably fade, and suddenly the guidestar escapes. To solve this problem, I built a small electronic box that takes over this job.

To create this device, a 115 x 900mm guiding telescope is mounted on a 190 x 760mm Lichtenknecker flat-field camera with adjustable brackets. Via a beam splitter, the guidescope projects a star image on a reticle and on a four-quadrant photodiode. The four quadrants are used two by two to control right ascension only. The star image is kept in the center of the dividing line between the segments for minimum error signal. The photocurrent (1 to 10 picoamperes) is amplified and taken to a switching amplifier which controls the fast/slow buttons of the drive corrector through relays. Direct use of the error signal to control the speed of a DC motor drive is much more accurate. The speed of my DC motor drive is varied continuously to produce a smooth telescope motion. The motor speed varies to compensate for gear train errors and seeing variations as seen in a correction signal recorded in fig. 7.

My best measured guiding accuracy was 1.2 microns during 20 minutes. The sensitivity is enough to guide on an 11th magnitude star with an 8-inch telescope, but for dependable operation, a star two magnitudes brighter should be chosen. As an example, inspect the automatically guided picture of the Cone Nebula (fig. 8), enlarged 18 times from the negative in this reproduction. The exposure is 60 minutes at f/4 on hypered 2415 with an RG2 red filter.

The electronic details of the autoguider are probably not interesting to most telescope builders, but those who *are* interested in building one may write to me for a copy of a pamphlet I prepared several years ago for amateurs in Holland and Belgium. It contains a detailed description of the autoguider's circuits. I will gladly make it available to interested amateurs who send a self-addressed envelope and $2 to cover the out-of-pocket expense of postage and duplicating.

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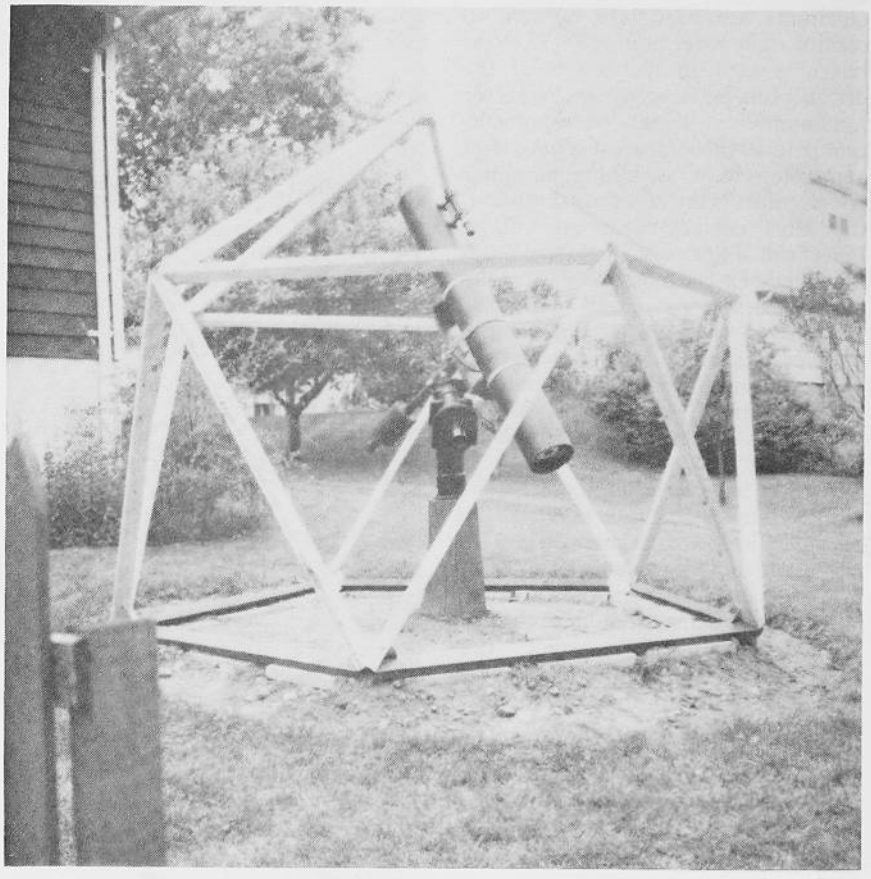
■

Building a Geodesic Observatory for Under $200



While browsing in an arts and crafts shop, I came across an advertising brochure left on the sales counter that expounded the virtues of a metal heavy-gauge steel plate called a "Starplate."* Thinking it might have something to do with astronomy, I read the first few lines and discovered that this simple plate — by means of its channelled construction to hold 2x4 lumber — would permit construction of simple geodesic dome structures from 3′ to 13′ tall, depending on the length of the boards used.

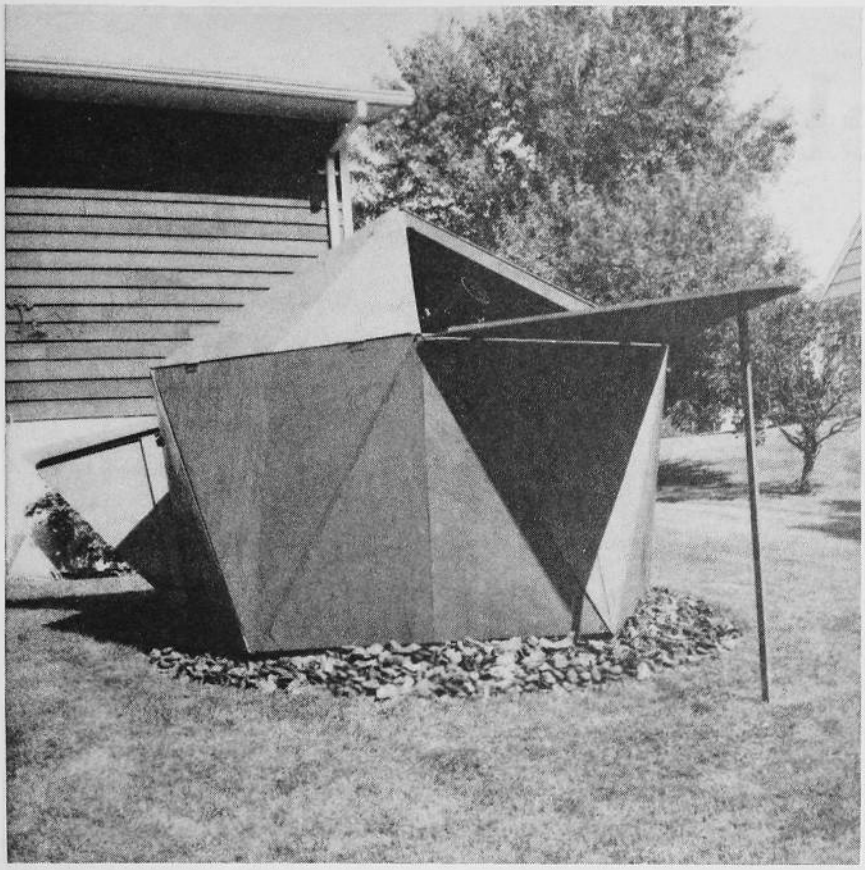
Reading on with increased interest, I discovered that a complete geodesic structure could be built with only 25 equal-length 2x4s, which would require a hole at each end for a carriage bolt through a Starplate. Eleven Starplates were needed in all.

The simplicity of the structure struck me (especially because of my limited carpentry skills), and I wondered about using such a building for a small observatory for my 6-inch reflector. I had been having an on-going discussion with my wife about building an observatory, which of necessity would have to be located fairly close to the house. None of the previous designs I had shown her impressed her, but this one caught her imagination and she actually encouraged me to build it.

I took the brochure home, studied it, and determined that the entire observatory could be built for under $200 (Fall 1982 prices). There would be no frills; each of the five sections would have a hinged roof for viewing, and plywood construction would be used throughout — except for the floor, which would use ¾″ flakeboard sheathing.

I sent off a letter to the Starplate dealer, and ordered a box of eleven starplates (one size fits all structure sizes). In the meantime I purchased the 2x4s, bolts and sheathing, and started to plan out the design. A tree stump was located exactly where I wanted to put the building, so I decided to use this as the pier for my telescope. The stump was cut off 2′ from the ground, calculated to permit the telescope to swing through all positions without hitting the roof of the building (or the floor), and my telescope mount, made from pipe fittings, was transferred from its portable stand to the tree stump. An adjustment screw was added so that it could be oriented toward Polaris over a sufficient range.

I staked out the area for the building, cleared the grass and leveled the ground. Ordinary patio blocks were used directly on the ground to form a foundation around the perimeter of the building. The ground is fairly firm and rocky in my yard. This procedure may require some alteration for soft ground, such as the use of concrete blocks — even a poured concrete base if you want

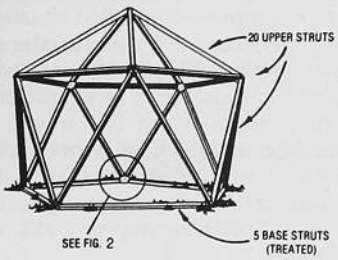


STARPLATE™
Building Systems

Fig. 1

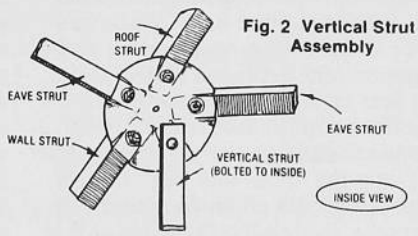
Basic Framework

Materials —
(5) Struts (treated) for base
(20) Struts for roof and walls
(50) 5/16" Carriage bolts, nuts & washers



All pieces are the same length

Fig. 2 Vertical Strut Assembly



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**Starplate™ Frame connectors and construction plans may be obtained from:*
East-West Design, Inc.
Box 6022
Madison, WI 53716

to get fancy.

A week later my Starplates arrived, and with them an excellent set of instructions and formulas for construction of a variety of sizes and shapes of geodesic domes. Keeping my design simple, the boards were trimmed to their final size (the 25 2x4s are identical, 5′ in length). The entire structure framework was assembled in less than two hours, using only a hammer, a drill, and a pair of pliers to tighten the nuts to the carriage bolts. I oriented the opening that would be the entrance door toward the house, which would block the northwestern view of the sky.

After assembling the structure, the outside panels were cut out and the lower ones were nailed to the 2x4s. The upper panels were hinged so that each (except the panel facing the house) could be lowered for viewing its sector of the sky. A screw-eye was added to the top of each hinged panel, so that by means of a 6′ pole with a crew-hook at its end, any panel could be opened and braced to the pole, which holds it open. A half-door was added beneath the fixed roof panel. It requires bending to get into the observatory, but this should be no problem, unless you are over 6′.

The dome was stained the same color as the house (and my wife added the banner on top), and as yet I have had no complaints from the neighbors — in fact some have brought their friends over to see the observatory. The building was very easy to construct, and with some ingenuity can probably be improved by anyone skilled in carpentry (I am not). The top could probably be separated and mounted on rollers to permit rotation (then only one sector would have to be opened), or something like fiberglass could be used on the outside to make it light enough to be a completely portable observatory. Anyhow, it serves my needs right now, and certainly does the job of blocking stray light, and keeping out the majority of wind, animals, bugs and other forms of nature designed to drive the amateur astronomer indoors!

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■

Telescopes for Microcomputer Control

The microcomputer revolution is gradually inching its way into the domain of telescope making. And as all faithful TM readers know, microcomputers are useful in ray tracing, logging photoelectric data, and other number-crunching tasks. Of particular interest, however, is the control of telescopes by microcomputers. While existing telescopes can be modified for microcomputer control, the true telescope makers are likely to be most interested in what sort of telescope could be designed if it were a given, right from the start, that the telescope would be controlled by a microcomputer.

The field of amateur-built, microcomputer-controlled telescopes is in its barest infancy, so it is too soon to say what sorts of mounts and drives will eventually evolve and in the end prove to be most popular and useful. It is not too soon, however, to discuss some of the issues involved, and that is the primary intent of this paper. Nor is it too soon to describe specific and functioning amateur-built systems; to this end, we describe the system built by one of us (Boyd): a fully-automatic telescope that makes unassisted photoelectric observations of variable stars.

Our emphasis will be almost totally on the mechanical aspects of mounts and drives. This is not to suggest that the control electronics and software are not important — they are *most* important — but they are extensively treated in a new book, *Microcomputer Control of Telescopes* by Trueblood and Genet, due to be published by Willmann-Bell in June 1984.

Mounts

From the standpoint of computer control, the most important distinction between mounts is whether or not they are equatorial. If they are equatorial, then a near-constant driving speed in a single axis suffices for tracking. If they are not equatorial, such as the alt-azimuth or the alt-alt mounts, then tracking a star becomes a very difficult task — although one not entirely beyond the capabilities of advanced TMs. In the interests of mechanical and computational simplicity, or unless there is some overriding reason for doing otherwise, an equatorial mount should always be preferred.

A further simplification from the viewpoint of the microcomputer comes from supplying the constant stellar rate motion to the equatorial mount external to the microcomputer itself. While this can be done with a small motor and differential, the approach suffers from large gear errors. A better method is to generate the stellar rate with a crystal-controlled oscillator, and electronically "add" to the base rate any control signals from the microcomputer. In either case, the result is the same: as far as the microcomputer is concerned, the sky does not turn. A non-rotating sky greatly simplifies the software.

After going to considerable expense and trouble in designing and building a microcomputer-controlled telescope, most TMs will want to be able to put in the coordinates for their favorite objects and then find them centered in the eyepiece (or at least within the field of view of the main telescope) after the control system does its thing. This is simply not going to happen without solid piers and properly aligned mounts.

Provisions must be made for four fine adjustments. Besides the azimuth and elevation of the polar axes, there needs to be an adjustment to make the declination axis perpendicular to the polar axis. Furthermore, it must be possible to make the optical axis perpendicular to the declination axis. This can be done by moving the secondary mirror laterally across the tube. If the secondary mirror is fixed on the back of a corrector plate, then the entire optical assembly (or the telescope as a whole) may need to be tilted. Although these adjustments could be made in software, again the software is greatly simplified if it only has to navigate within a precisely aligned and correctly oriented equatorial coordinate system.

Next, the telescope must be "stiff." Microcomputer control opens up many interesting capabilities, such as rapid movement between stars, quick search patterns, and even the automatic finding and centering of stars. In the automatic photoelectric telescope (APT) to be discussed later in this article, the telescope makes about 100,000 different movements in a single night — most of them very short and rapid movements used to search for and center stars. In such a computer-controlled situation, a sloppy telescope that vibrates after a fast stop simply will not do — it would spend too much time after each move settling down. What is required is a telescope in which all vibrations are damped out within one-tenth of a second after any perturbation — whether a sudden stop or a jolt, wind gust, etc.

Few amateur telescopes up to now have been built to this standard. When a telescope is tapped, it vibrates back and forth several times before it settles down. If the frequency of vibration is high, then the time taken to settle down is short, while if the frequency is low, the time is long because the telescope usually goes through a fixed number of oscillation cycles before settling down to within an acceptable error band about the desired position.

So what is desired is a telescope

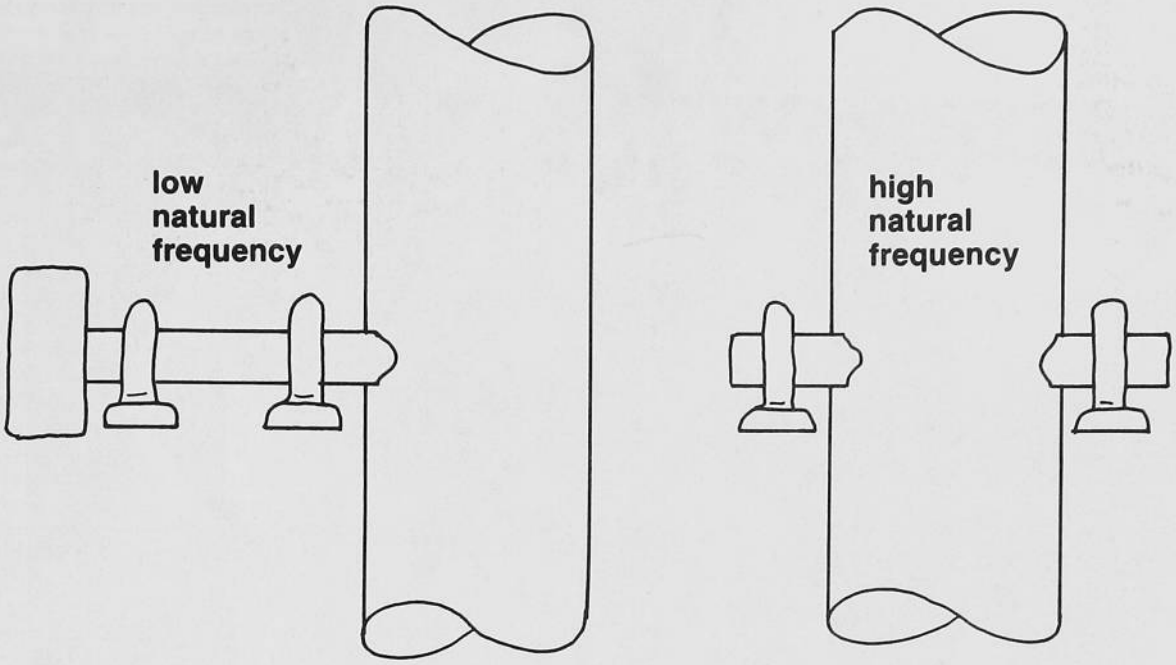

Fig. 1. *How to prevent a 2"-diameter steel shaft from becoming a spring.*

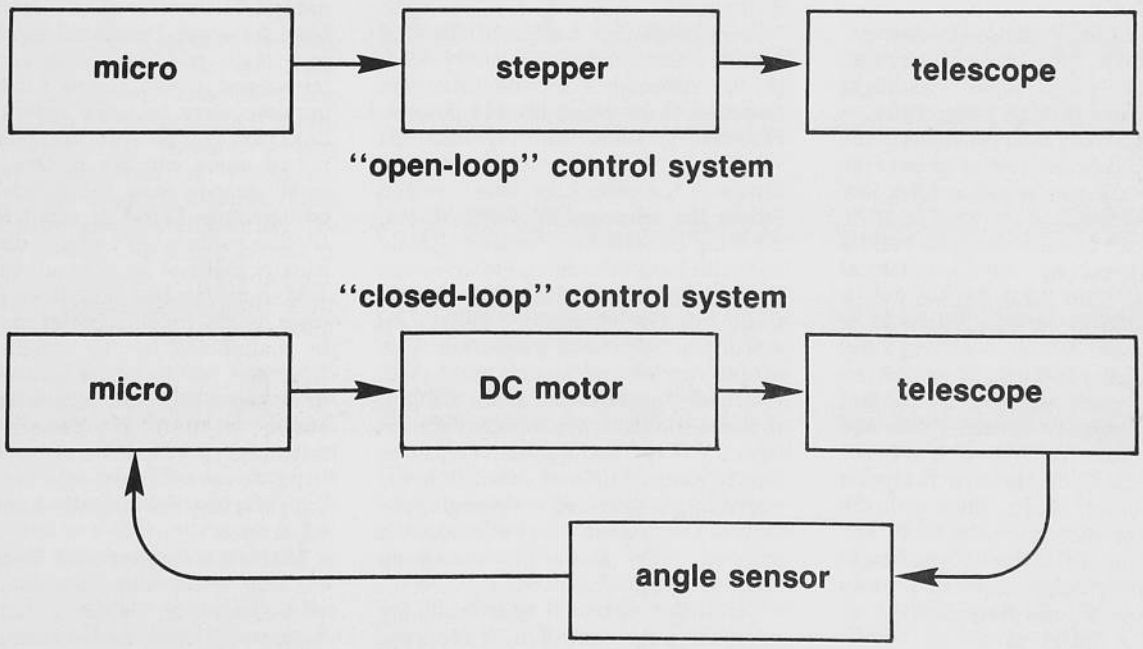

Fig. 2. *Open loop is simpler, but closed loop is more flexible.*

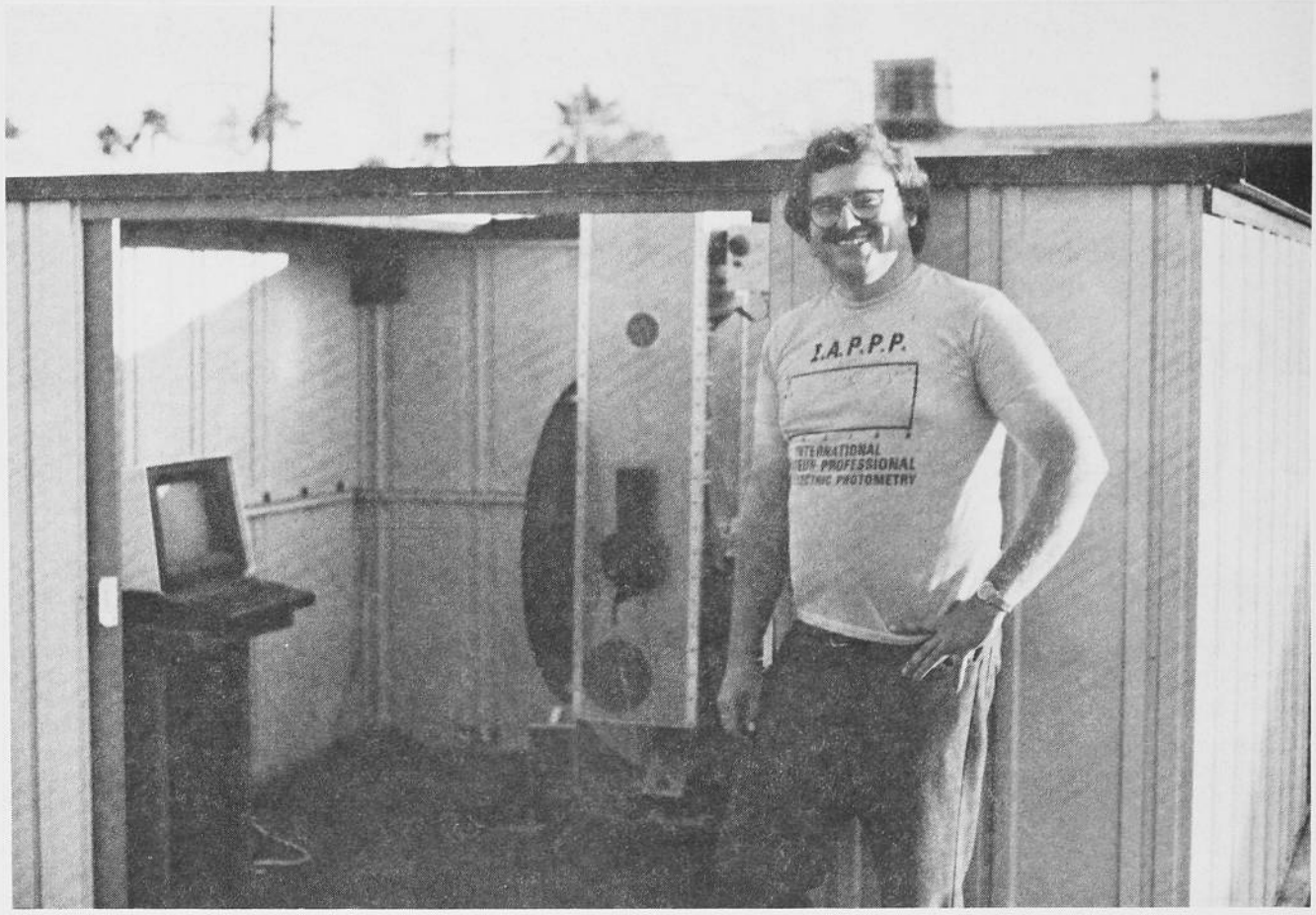

Fig. 3. *Louis Boyd by his telescope in Phoenix.*

mount with a high "natural frequency" — a soprano in the world of telescopes is superior to a bass. Rigidity and light weight make for high frequencies — with the necessary mass that makes the mount rigid concentrated as close to the axes of rotation as possible for a low moment of inertia.

There are two easy ways to build a poor mounting, one with a low natural frequency. The first is to use a nonsymmetrical design such as a German mount. With the telescope and counterweights at opposite ends of the declination axes, the whole structure becomes a gigantic spring. Forks and yokes are preferred. If motion in RA or Dec is transmitted through the polar and declination shafts, then with the telescope on one end of the shaft, and some portion of the shaft being free to turn, you have a gigantic torsion spring — and a low natural frequency.

Drives

From the viewpoint of a microcomputer, some types of drives are much better than others. For instance, consider a telescope drive with a sector gear in RA and a tangent arm in Dec. Although people don't mind resetting sector arms or recentering tangent arms, getting a microcomputer to do it is very difficult.

Also, consider backlash. To the human operator, the momentary delay in the telescope's motion when its direction is reversed is unimportant. However, for some control systems, this "dead-band" results in positioning errors — the computer loses track of where the telescope is. Furthermore, allowing the telescope to move freely back and forth uncommmanded — even a small amount — drops the natural frequency. To eliminate backlash on worm gears, a preload weight, spring or torque motor are sometimes used. However, this makes it more difficult to move the telescope in one direction than the other, and the motor must be slowly ramped up and down to avoid overriding the preload or damaging the worm gear when the telescope is stopped. This limits the maximum acceleration during slew.

Telescopes designed specifically for microcomputer control must avoid the "final gear backlash" problem by doing away with final gears. At least three approaches have been used to eliminate final gears. They are the *disk and roller, chain and sprocket,* and *cable and drum.* Chains and cables have a certain amount of "give" to them, and on larger telescopes this can seriously degrade the natural frequency of the drive; they have, however, been used successfully on small microcomputer-controlled telescopes. Chain drives suffer from periodic error to some extent as the links pass over the sprocket teeth. While not of much concern in Dec, even a small periodic error in RA can be very bothersome. Lastly, a small roller in friction contact with a large disk (both usually made of steel) is not only very stiff, but also has very little periodic error. In RA, friction contact can usually be maintained by the weight of the telescope, but in Dec a constant force must be provided, and this may require some mechanical cleverness. A roller/disk drive in RA and a chain drive in Dec are likely to be worth considering for small home-built telescopes.

Motors, Clutches and Encoders

Again from the viewpoint of a microcomputer, when it comes to motors, clutches, and encoders, there are two basic types of systems. The simplest type has no clutches or encoders at all, and has only one stepper motor per axis. The strategy here is simple: if the computer knows where the telescope is to begin with (such as a calibrated home position or manual

positioning on one bright star), then by issuing the right number of steps in RA and Dec, the microcomputer can move the telescope anywhere it wants to. The requirement is that each step move the telescope a small amount in the sky, and that nothing else be allowed to move the telescope — e.g., no clutches, slewing motors, etc. are allowed.

The second approach is to place some sort of angular position sensor on each of the axes and then move the telescope with any sort of motor or combination of motors until the angle sensor says the telescope has arrived where it ought to be.

These two approaches are shown diagrammatically in fig. 2, and are sometimes referred to as "open loop" — the single stepper per axis approach — and "closed loop" — where the angle sensors feed back position information. In both approaches, the ultimate result (and accuracy) is the same because there will be an astronomer's eye (or the photoelectric "eye" in an automatic system) that will see and perform the final centering of each object.

The main advantage of the open-loop stepper approach is its simplicity in both hardware and software. Its main disadvantage is that the top speed of the stepper motor and the smallness of the step size limit the slew speed of the telescope. Although this can be overcome by having a separate stellar-rate drive motor acting through a differential, differentials also introduce problems.

The closed-loop approach is more flexible in that any type of motor, in any number, can be used. The closed-loop approach can be inexpensive if it uses potentiometers for position sensing (somewhat inaccurate), or very expensive if high-accuracy optical disk encoders are used. In either case, the software is more complex than that in an open-loop system. We predict that TMs will thoroughly explore both approaches over the next several years.

Automatic Photoelectric Telescope

Shown in fig. 3 is an overall view of the automatic photoelectric telescope at the Fairborn Observatory West in Phoenix, Arizona. The telescope is located in a converted garden shed with a motorized roof that moves off to the left. Inside the shed is a terminal; the telescope itself can be seen with the large declination disk to the left of the telescope, an elbow finder telescope in the middle of the main telescope, and the permanently mounted photometer at the upper right (Newtonian focus) of the telescope.

The fork mount, telescope base, and RA disk and chain are seen clearly in fig. 4. The bottom end of the telescope

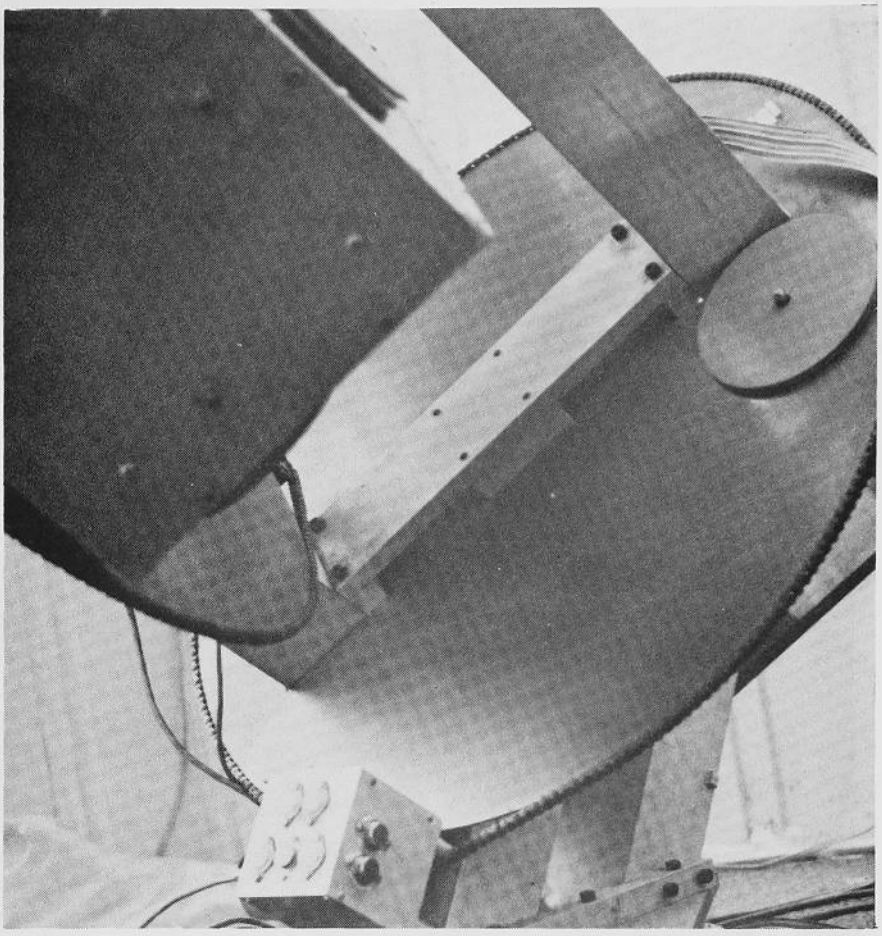

Fig. 4. *Fork and 32"-diameter RA drive disk.*

and a portion of the declination disk and chain can also be seen. The telescope base is triangular, and is fabricated from a piece of thick magnesium alloy sheet that happened to be handy. The aluminum box with the power transistors on the outside contains the anti-backlash worm gear that does the initial reduction, as well as the stepper driver electronics.

Not visible, but on the left side of this box, is the Slo-Syn stepper motor that drives the telescope. The sprocket that drives the chain is on the far side of the box. The chain is the same stuff used for bicycles and light industrial applications. The chain fits loosely enough around the aluminum disk so that if the telescope is forcibly moved by hand, the chain slips on the disk rather than ruining the gears. As can be seen, the fork not only has a crosspiece in front of the large RA disk, but it passes through the disk and continues on to another crosspiece behind the south polar bearing.

The extension of the fork shows more clearly in fig. 5. Here the RA disk is on the left, with the north polar bearing right up against the disk. Coming up from lower left are the two "pillars" from the base plate. There is a solid aluminum bar across the top of the two pillars. At the lower right is the south polar bearing, and behind it is the solid aluminum bar between the two extensions of the forks. One fork is seen at the upper right, while a small portion of the other fork can be seen between the pillars coming up from the base plate. There is no polar axle in this mount.

Details of the declination sprocket, chain, and disk edge show clearly in fig. 6. At the bottom of the photograph is the RA disk drive, while on the left can be seen one of the forks and the front crosspiece between the forks. The sprocket can be seen extending out from the declination drive box that contains a reduction gear, stepper driver, and stepper motor (the driver electronics and motor cannot be seen in the figure). The edge of the declination disk can be seen. Note that the sprocket is located quite close to the edge of the declination disk to minimize the amount of chain not on the disk itself.

Although you can't tell from looking at it, the stellar rate drive pulses are supplied from a source outside the microcomputer and electronically added in. Thus from the viewpoint of the microcomputer, the sky is fixed.

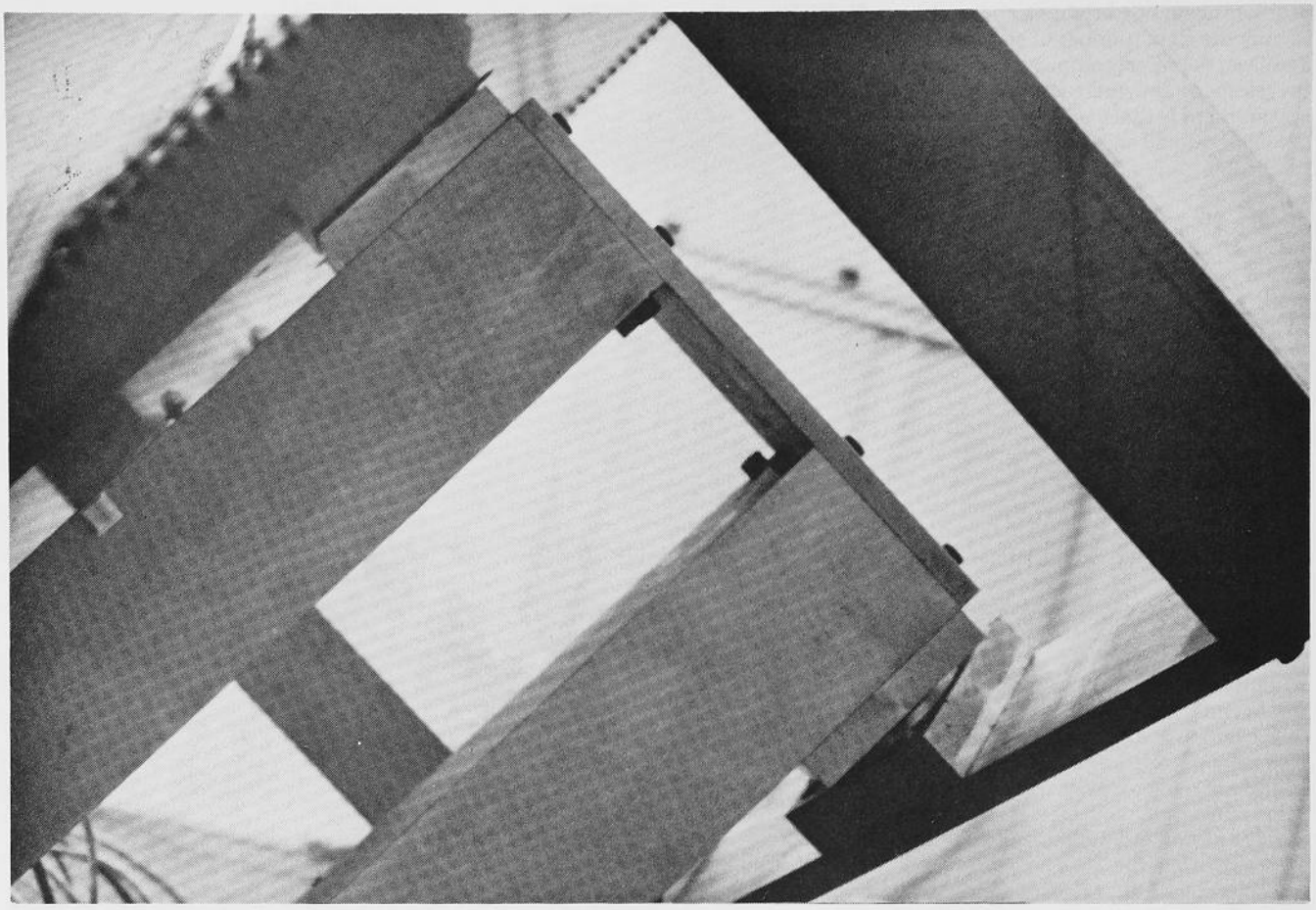

Fig. 5. *Rear extension of fork and polar axis bearings.*

Movements in RA and Dec are orthogonal to each other, because precise adjustments have been made between the Dec and polar axes and between the optical and Dec axes.

This fork mount has a high natural frequency. Not only is it a symmetrical design, and without significant counterweights, but motion is transmitted from the drive to the telescope from the outer portions of large disks rather than through small shafts. The use of light-weight material (aluminum), generous cross-sectional areas, and a modified fork all contribute to the high natural frequency by providing a stiff, yet light-weight structure.

The drives in each axis are identical. A $10 surplus Slo-Syn stepper motor turns 1/400th of a revolution on each command received from the microcomputer (half-step mode). This

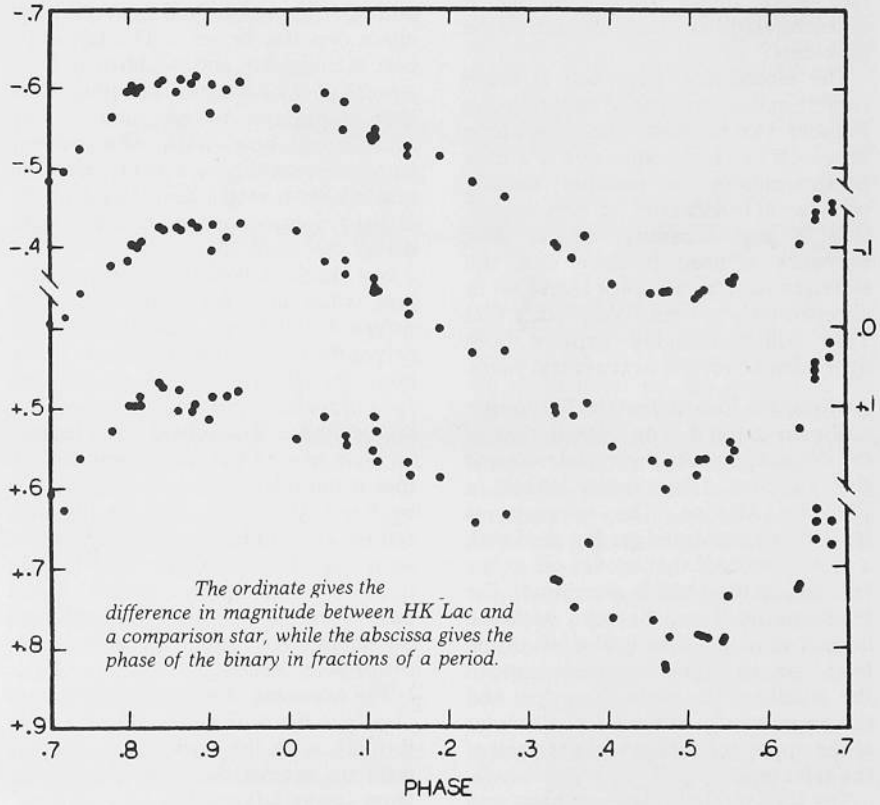

Fig. 7. *Light curves of the spotted eclipsing binary HK Lac. The top, middle, bottom curves were taken in the V (visual or yellow), B (blue), and U (ultraviolet) passbands of the photometer. This eclipsing binary has a 24.5 day period and was observed over three cycles from October through December, 1983, with the Automatic Photoelectric Telescope.*

motion is reduced by a small anti-backlash worm gear — a gear split into two pieces which are loaded against each other with a spring. The motion from these is transmitted via small sprockets and chains to 32-inch diameter aluminum disks, 3/16"-thick disks that were picked up surplus for $5 each. There is a significant periodic error in RA (due to "cogging" in the sprocket) that would not be helpful in photography, but the automated photoelectric telescope (APT) rarely spends more than 30 seconds on a star, so the periodic error doesn't have time to take effect. There are no clutches, separate slew motors, or encoders in the system.

Every clear night — and Phoenix has plenty — the APT starts itself up, moves to where it thinks the first star is, then looks for the star and centers it with its photoelectric "eye." It then makes measurements of the star's brightness and color. Then it moves on to the next star, and the next, and the next, all night long. When dawn arrives, it shuts itself down. Currently it is working on a sizable program of binary stars with star spots and on suspected variable stars. This is a cooperative program with Douglas S. Hall at Vanderbilt University. A light curve obtained by the APT is shown in fig. 7.

Lessons Learned

While the automatic Photoelectric Telescope just described works well enough — indeed, it is a pioneering development — one of the objectives of the project was to determine where improvements could be made. While most of the improvements being made on the next generation of APTs are in the area of electronics and software, there are three improvements being made in the mount and drive that would be of interest to TM readers.

First, the modified fork, while perhaps increasing stiffness somewhat, is not worth the effort. The extension of the fork limits the motion of the telescope in RA, and makes the telescope difficult to assemble and disassemble. A well-designed and stiff but light regular fork (or yoke) is recommended.

Second, the aluminum disks and steel chain have different coefficients of expansion with temperature. The result is that the chain tension must be adjusted more often than it would have to be if both materials were the same. As they don't make aluminum chains, this suggests a steel disk.

Finally, while the significant periodic error in RA is of no consequence for automated photometry, many would find it irritating. The best solution, we think, is a disk and friction roller for the RA drive. The weight of the telescope and fork will maintain good friction contact.

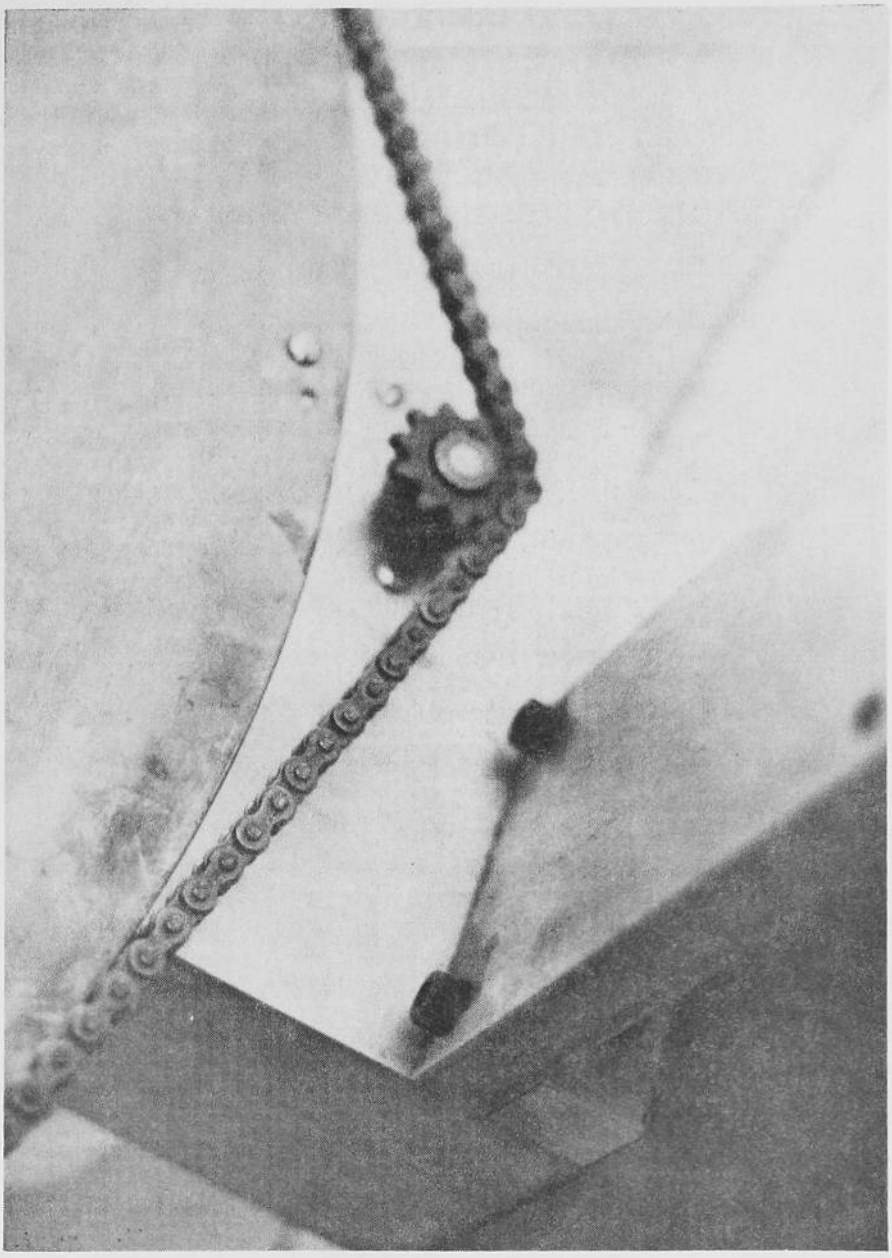

Fig. 6. *Declination sprocket, chain, and disk.*

Frank Melsheimer at DFM Engineering has designed a mount for small telescopes that uses 15-inch diameter steel disks in both RA and Dec. The mount itself is made from highly rigid aluminum castings. This well-designed mount is ideal for computer-controlled telescopes, and is worthy of careful study. (A future issue of TM will discuss this mounting in detail.)

Conclusions

From the viewpoint of microcomputer control, telescope mount and drive requirements are somewhat different than they are for telescopes without such control. Astronomers are generally more forgiving, slower, and smarter than are microcomputers, and thus are not as demanding of their mounts and drives. We should not be surprised if a new breed of small telescopes — both amateur and commercial — appears over the next few years. Telescope judging contests and advertisements might start talking about "natural frequency," and in final drives, worm gears could end their 200-year reign.

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c/o Fairborn Observatory
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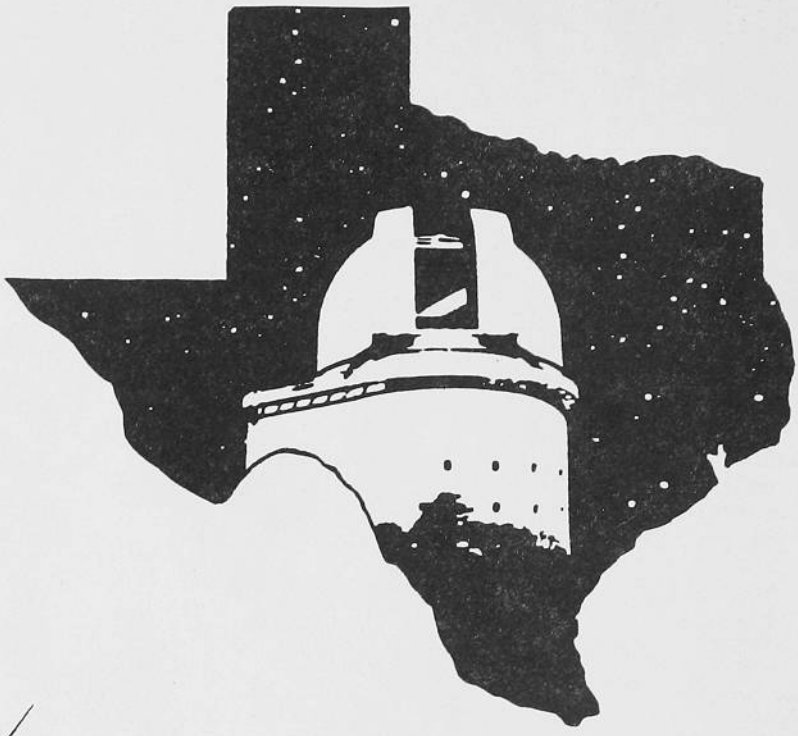
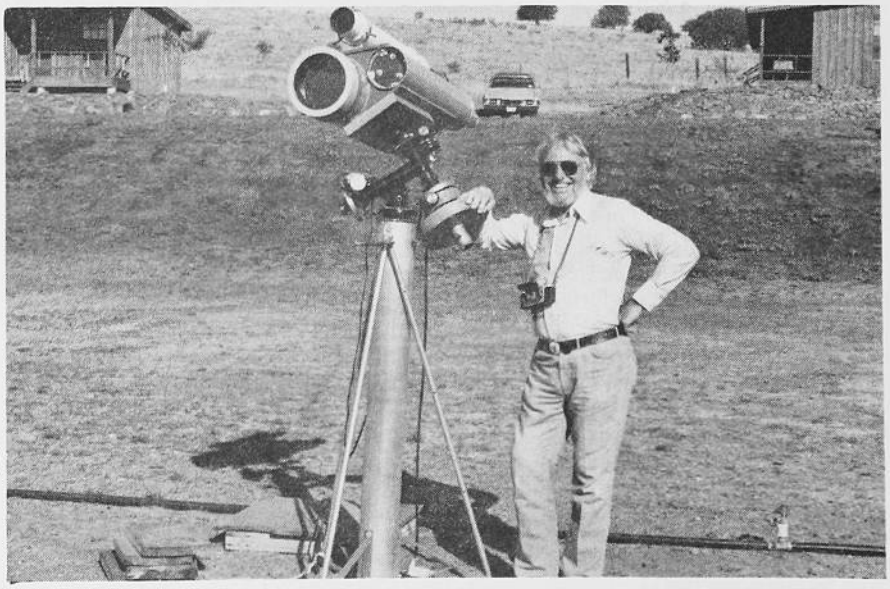


STAR PARTY 1983

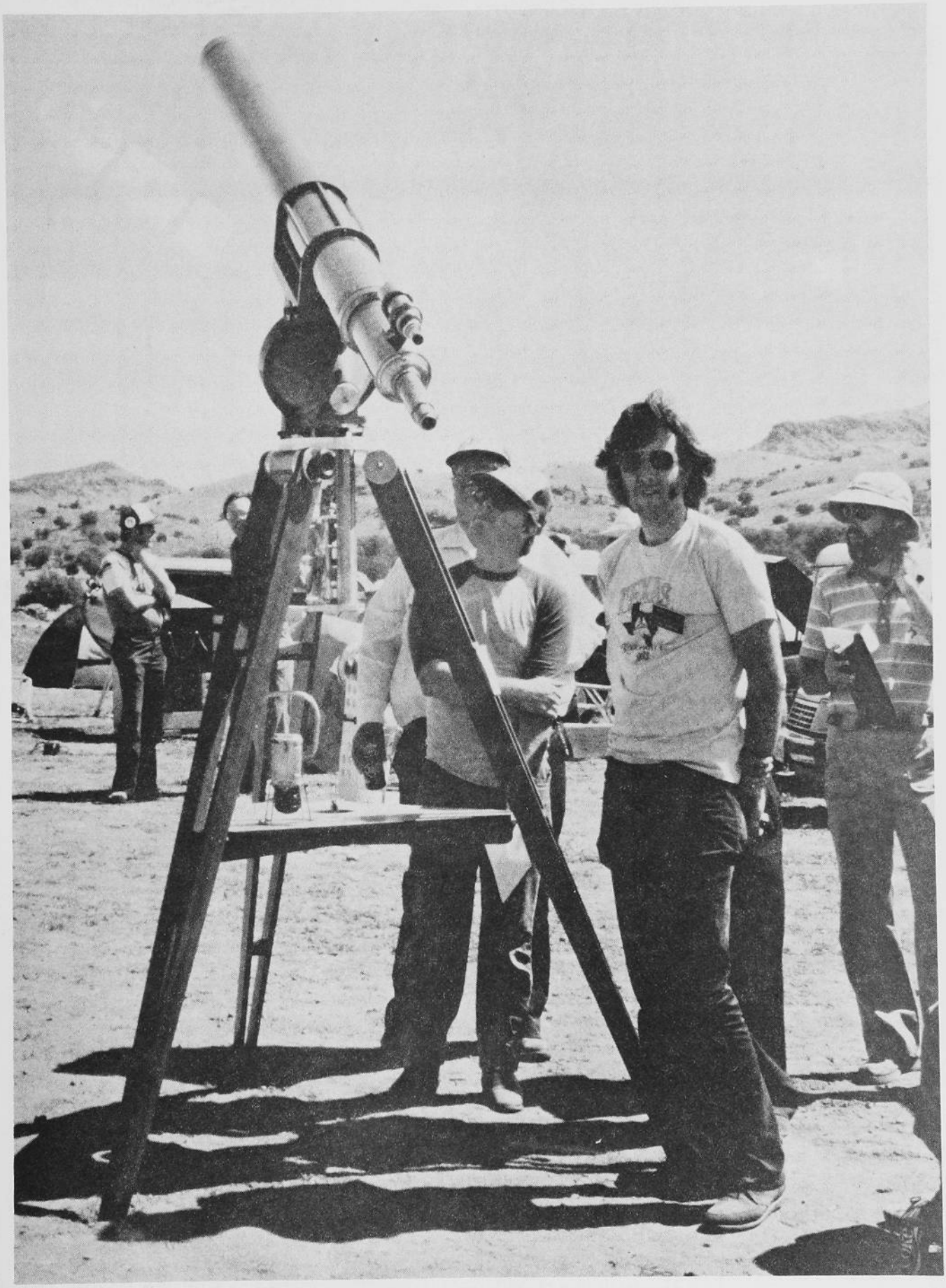
It seems that when Texans decide to do something, they do it with great gusto. And so it was when, in 1979, a group of Texas amateurs, frustrated by the inferior skies of and great distances to Stellafane and Riverside, banded together and decided to hold a statewide star party. Although it didn't become a full-fledged national gathering until 1982, the Texas Star Party was born.

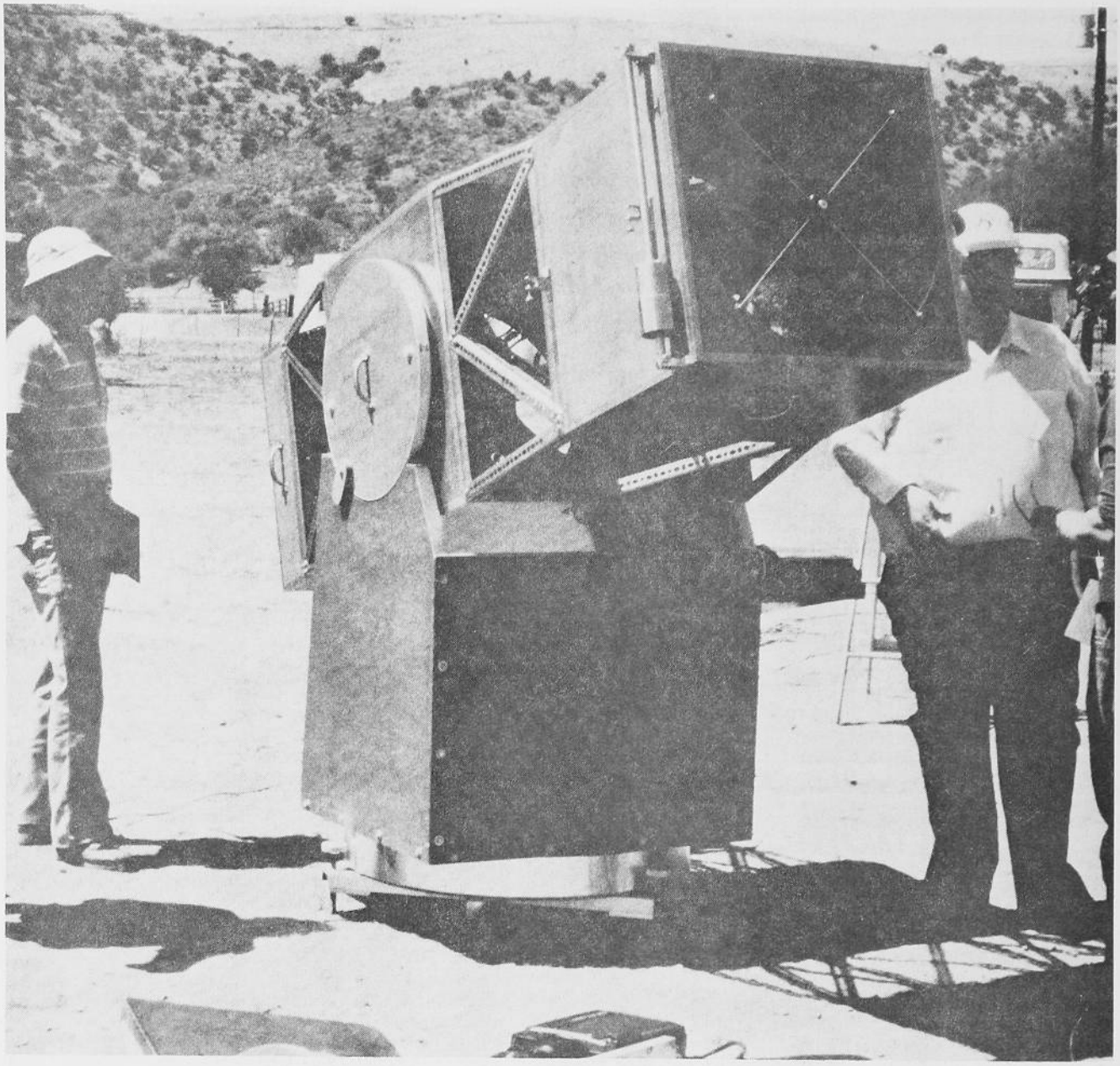
By 1982, when the event started to grow at full throttle, over 400 amateurs attended from all over the country. This past year, on June 8 through 12, a similar number showed up. Why do



Californian Kevin Medlock and 6-inch f/15 refractor. Photo by Bruce Lundegard.

Sherman Schultz of Macalester College in St. Paul, Minnesota stands with his 8-inch f/10 refractor. Photo by Bruce Lundegard.



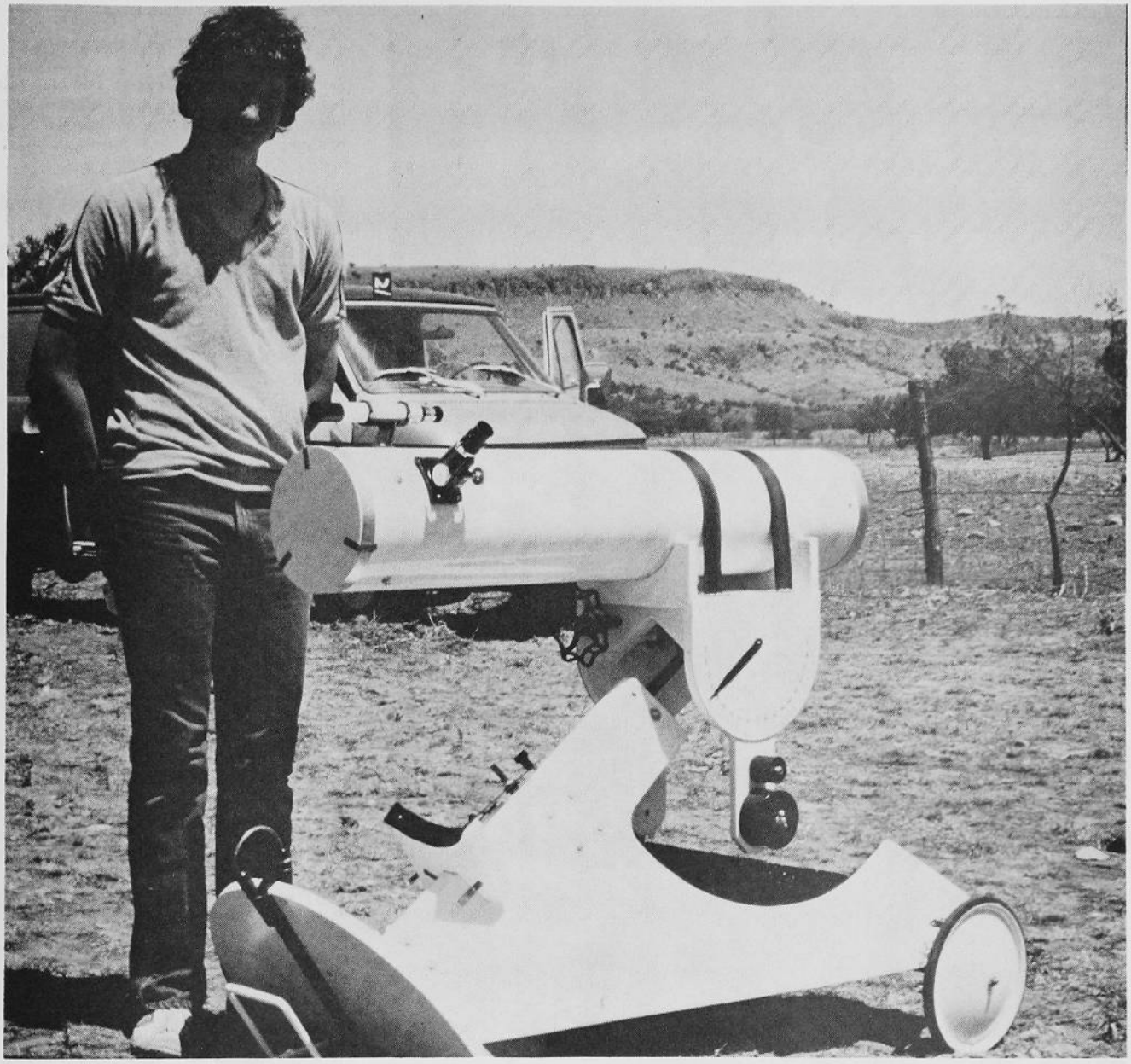


Standing with his massive 24-inch Dobsonian, the largest telescope at this year's TSP, is Andy Saulietis of Houston. This telescope offered exceptional views of faint deep-sky objects. Photo by Mike Jones.

such a great number of people travel to a remote spot out in the middle of the Texas mountains? Primarily they come because the skies at the TSP are terrific — and I base that on comparison with many observing sites in many different states. Located in Fort Davis, about five miles from the domes of McDonald Observatory, the TSP normally receives sunny hot weather during June days and velvety black skies and glaring stars during June nights.

This year was no exception: save for a couple of brief but violent squalls, we experienced fine weather, day and night. The excitement rampant among the delegates was easy to sense as dusk approached and observers geared up their telescopes. The majority of the crowd, as one might expect, had its eyes fixed on deep-sky objects. Many observers undoubtedly came away from that week with the best observations they had ever made. I walked around and looked at some particularly odd and faint objects like the supposed galaxy/quasar pair NGC-4319 and Markarian 205, the high-energy object BL Lacertae, a 16th magnitude supernova in galaxy NGC-4051, and the faint comet Sugano-Saigusa-Fujikawa (1983e). I remember that the central star in the Ring Nebula held steady with direct vision using a 16-inch Newtonian at 590x. The faint objects NGC-6888 in Cygnus and NGC-6822 (Barnard's Galaxy) in Sagittarius were easy targets for binoculars. Venus, seemingly as bright as the moon, persistently hung over the western horizon and disrupted our viewing. For most of the time it was up, it easily cast shadows on the ground!

But the entire gathering wasn't given over to rabid observing. Compared to the other two big gatherings, the TSP isn't so much an ATM meet, but still we saw examples of wonderful telescope design and construction. Lee Cain, for example, brought an innovative telescope with him from Houston. Utilizing Coulter optics, Lee built a 13.1-inch f/4.5 Dobsonian binocular, consisting of two parallel tubes and twin focusable eyepieces for psychologically satisfying three-dimensional views. The result, carried out to the extreme, worked magnificiently: 12th magnitude galaxies seemed to float, suspended

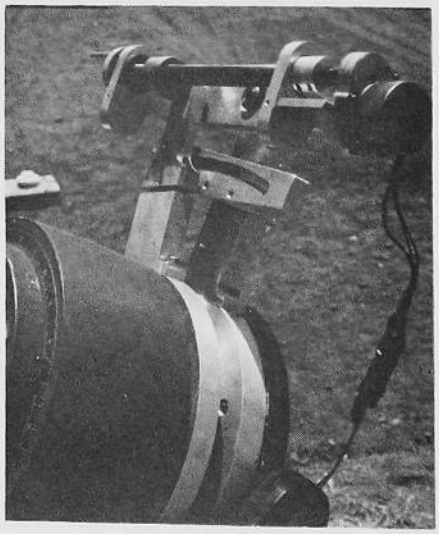


Danny Tyler of Fort Worth, Texas, poses with his first telescope — an 8-inch reflector mounted on an inverted German equatorial. Photo by Mike Jones.

among a glittering array of stars. The telescope was quite easy to move in both axes, regardless of its wide stubby construction. To view, you put your head between the tubes and look downward into the two eyepieces, which became straining after a while, but it was well worth it as the views were crisp and bright. For more on this telescope, see the article in TM#20.

Clearly thinking along the same lines, amateurs Jim Trexler and his son Ben brought all the way from Maryland twin 6-inch f/5 refractors which were mounted on the same fork. These scopes don't share a binocular image, but rather are mounted side by side to allow two observers to simultaneously view the same object. What a great idea for hunting really faint stuff — you and a friend can both stand there and argue whether or not that nebula or galaxy is really there!

Sherman Schultz from Macalester College in St. Paul, Minnesota brought no less than three telescopes. His mammoth 16-inch f/12 classical Cassegrain was accompanied by a 12-inch f/5 Dobsonian and a giant 8-inch f/10 refractor. The Cassegrain featured a broad fork mount design whose base was supported by sections of steel tubing, providing a rock solid support. The refractor carried with it two guide



Randy Albaugh's elaborate tangent arm assembly for his 14-inch SCT. Photo by Clyde Heath.

Lee Cain of Houston designed and built this ingenious Dobsonian binocular, which delivers crisp, relaxing pseudo three-dimensional views of deep-sky objects. Photo by Bruce Lundegard.

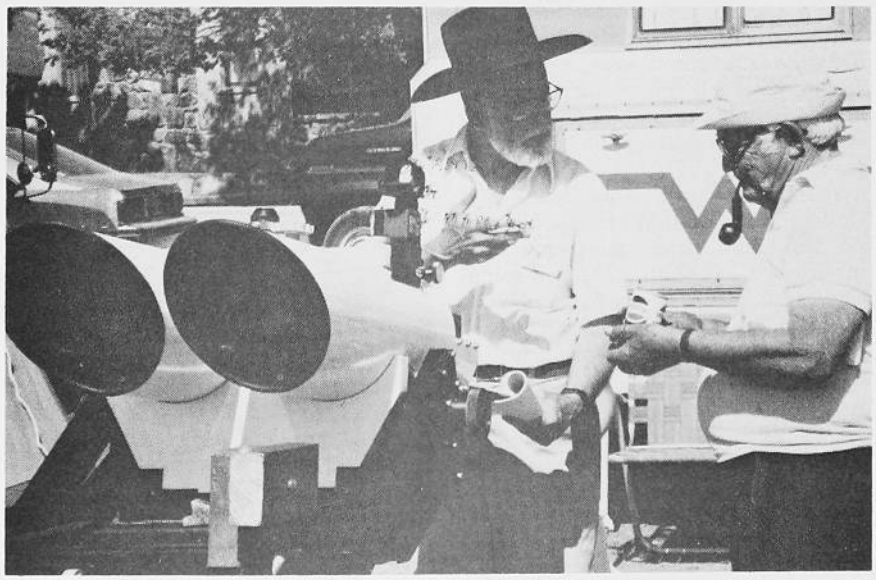
telescopes, perched on an equatorial mount atop a high steel pier.

Other Dobsonians lay scattered across the star party's sandy basin: Gil Machin from Kansas City brought a brightly colored 17.5-inch f/4.5 Dobsonian with Sonotube construction braced by dowels and a sturdy rocker. Andy Saulietis of Houston brought the largest telescope at the TSP — a 24-inch f/4 Dobsonian that offered crisp views of very faint and small objects. Its elaborate wood and steel construction made it appear something like a Civil War cannon.

Several other finely crafted scopes appeared at this year's TSP. Danny Tyler of Fort Worth brought an 8-inch reflector on an inverted German equatorial; I didn't get a chance to use this instrument, but heard good things about it. Kevin Medlock of Oakland, California brought his 6-inch f/15 refractor, training it on the planets during early dusk hours. Texan Randy Albaugh designed and built a tangent drive assembly for his 14-inch SCT; its brass and plexiglass parts were assembled with a high degree of precision.

Even though the Texas Star Party is not wholeheartedly an ATM meeting,

Gil Machin of Kansas City stands with his cleverly reinforced 17.5-inch Dobsonian with Coulter optics. Photo by Mike Jones.



Maryland amateur Jim Trexler is behind his twin 6-inch f/5 RFT refractors, discussing them with veteran deep-sky observer Walter Scott Houston. Photo by Clyde Heath.

clearly where there are observers, there are interesting telescopes. Next year's gathering will be held at the Prude Ranch, Fort Davis, Texas, on May 30-June 3. The velvety black skies and faint deep-space sights of the western Texas mountains will undoubtedly keep drawing active observers and ATMs coming back year after year, many for the best opportunity for observing they'll have for months or years.

Dave Eicher
c/o Deep Sky
625 E. St. Paul
Milwaukee, WI 53202

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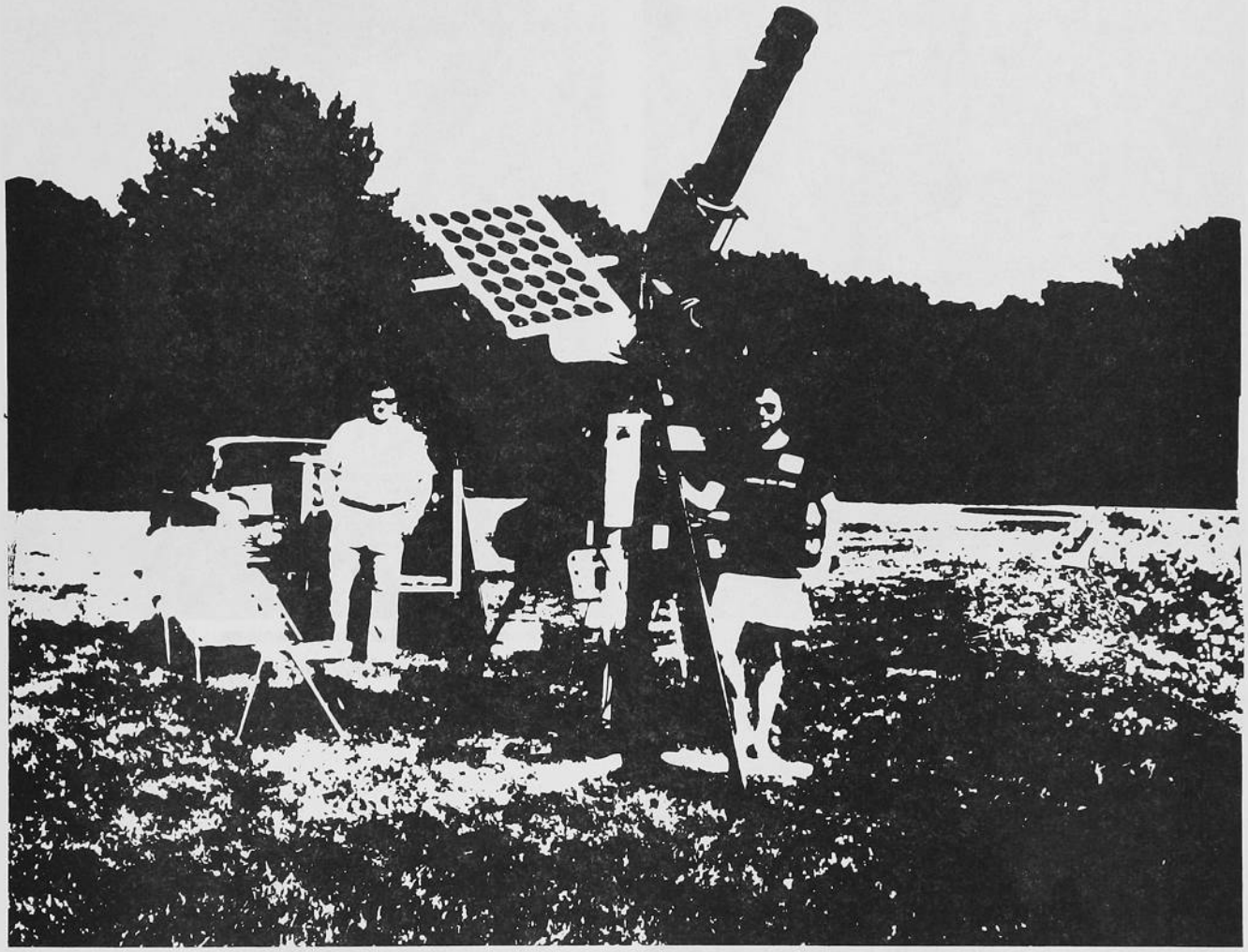


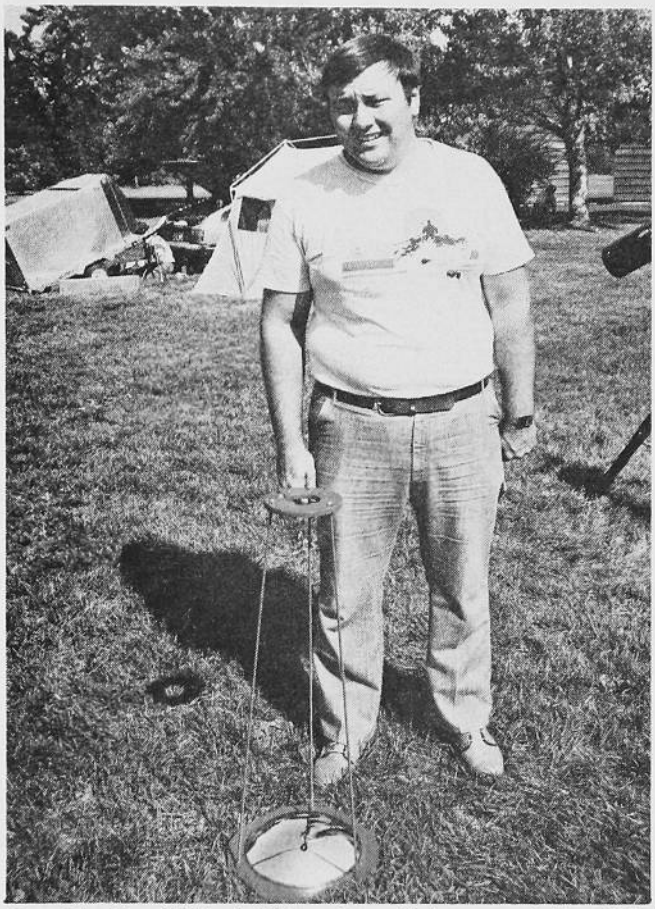
ASTROFEST 1983

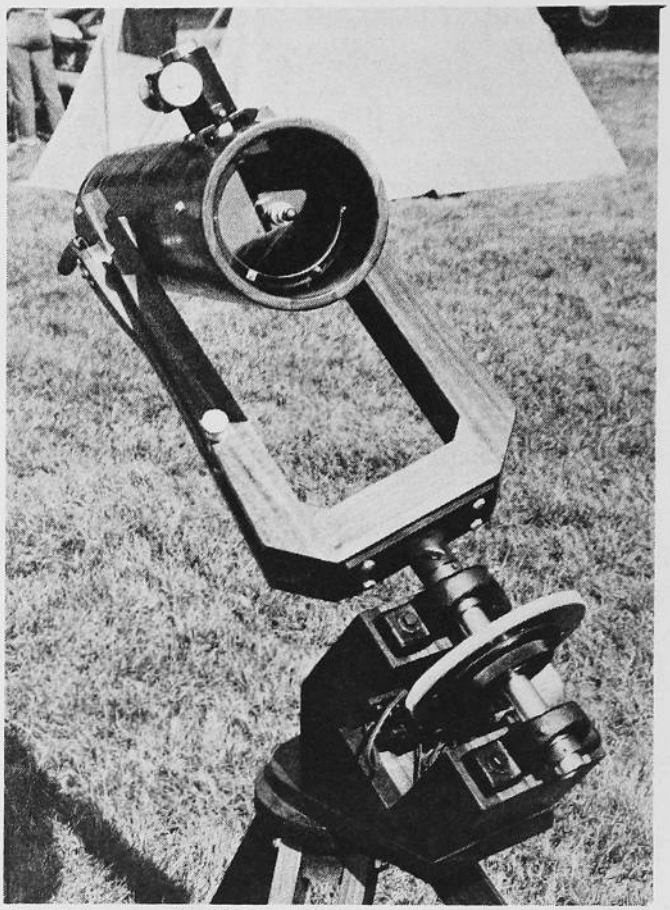
Astrofest became a major event for midwestern amateur astronomers this year. Attended by 164 people, Astrofest also attracted more than thirty different telescopes of almost as many different types. And it wasn't just telescopes gracing the field of Shaw-wan-nas-see 4-H Camp near Kankakee, IL, that made this year's Astrofest a success, but also two clear nights with plenty of observing!

Although a few clouds did move through the area Saturday afternoon, they cleared away by evening. Meanwhile, attendees were diverted by various talks and workshops on astronomy and telescopes making. In addition, they could enjoy a daytime view of the night sky in a portable planetarium called the "Cosmic Circus" provided by John G. Hanses, who travels throughout the country bringing the starry sky to daytime viewers.

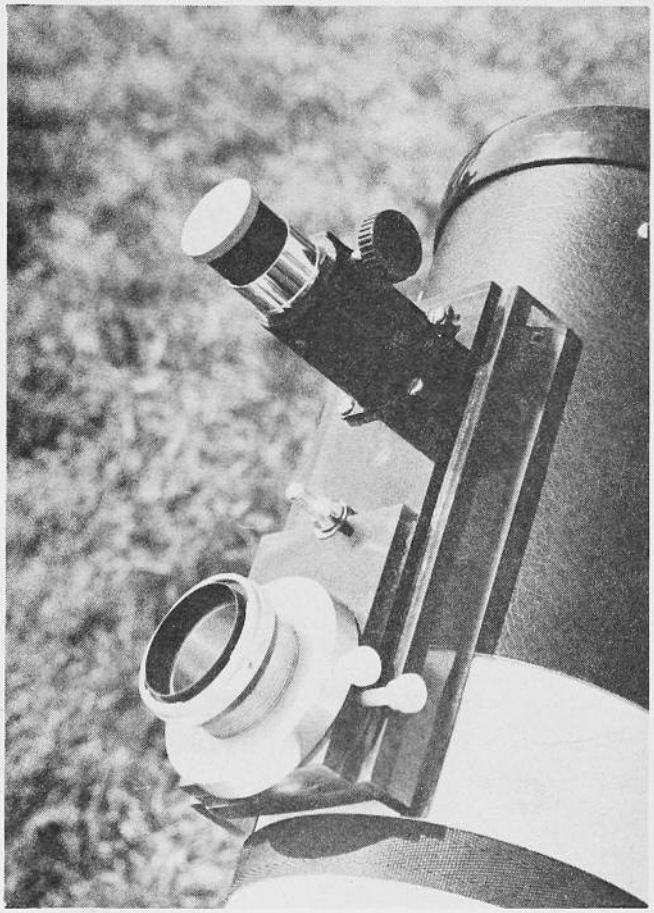
Observers who arrived on Friday night were able to view such splendors as the Veil Nebula, the Lagoon Nebula, and many other deep-sky objects. Those who tired of viewing (and few there were) watched the movie *Flash Gordon and the Purple Death*. Observing continued into the wee hours of Saturday morning when the crescent Moon rose over the telescopes, making deep-sky objects difficult, but not impossible, in the un-light-polluted skies over Shaw-wan-nas-see.

Saturday morning dawned bright and sunny with coffee and doughnuts available in the dining hall for the few





Steve Rismiller of Milford, OH brought an all-sky camera (left) and black walnut fork-mounted 4" f/6 Schmidt-Newtonian.

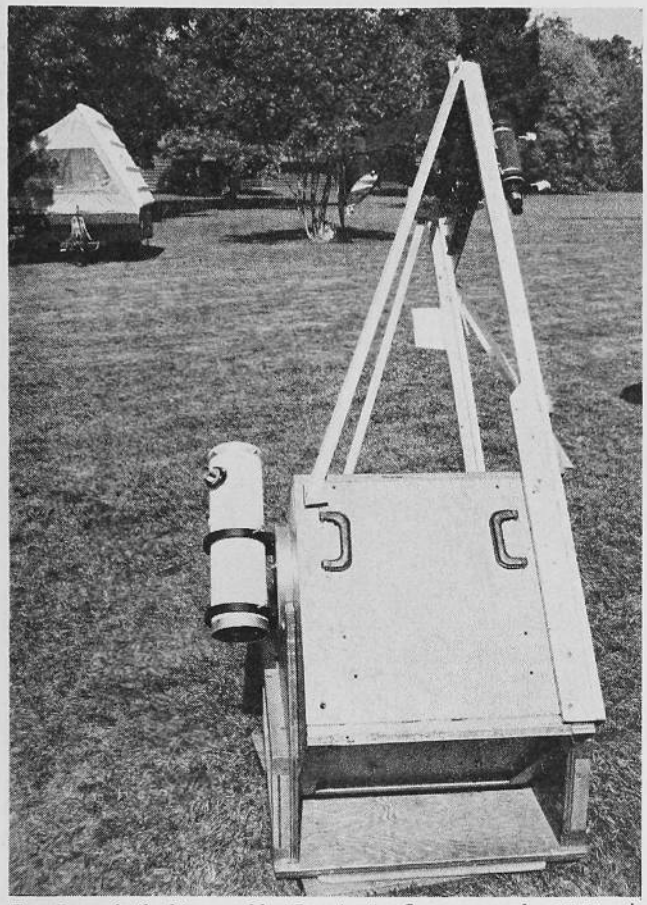


Jack Roach constructed an instant camera-eyepiece swapper. Upper plate rotates around the center bolt.

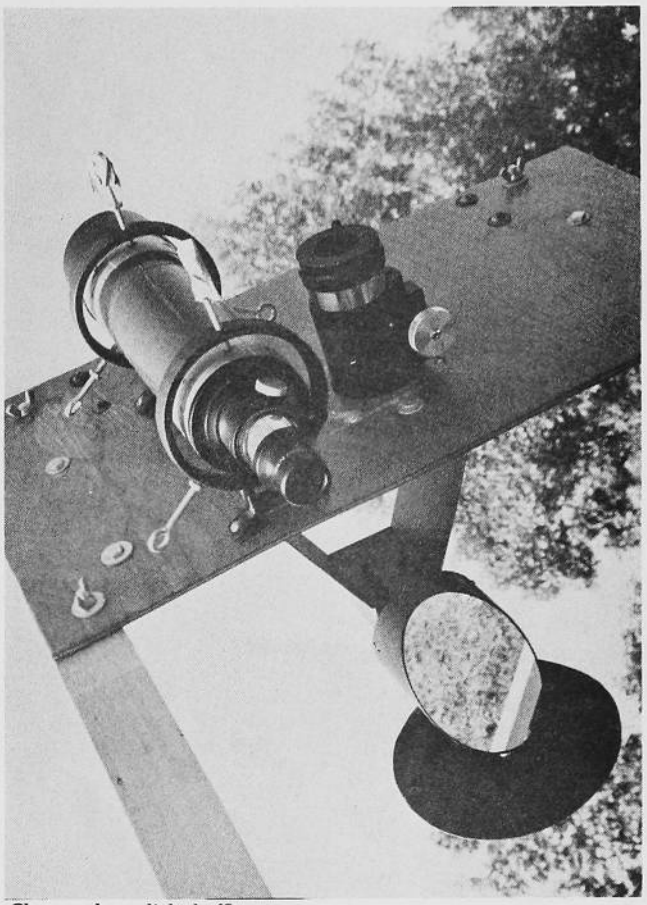
early risers who had not stayed up late observing. Many still had blurry eyes when Astrofest Chairman Jon Nehls gave the official welcome to more than 160 persons in the dining hall.

After the welcome came the morning papers session which included papers on "Perforating Clear Glass Secondary Holders" (Jack Brisbin), "Design and Construction of Small Refractors" (Robert Karas), "Astronomical Art" (Joan Hanke-Woods), "Drawing at the Telescope" (Daniel Troiani), and "Stellafane, 1983" (Jesse Carrol).

A catered lunch followed the morning paper session. After lunch, the Astro-Swap fleamarket opened, with myriad items for sale or swap. At the same time, many went to scrutinize the telescopes they'd been observing with the night before, and discuss the design and construction with the builders.

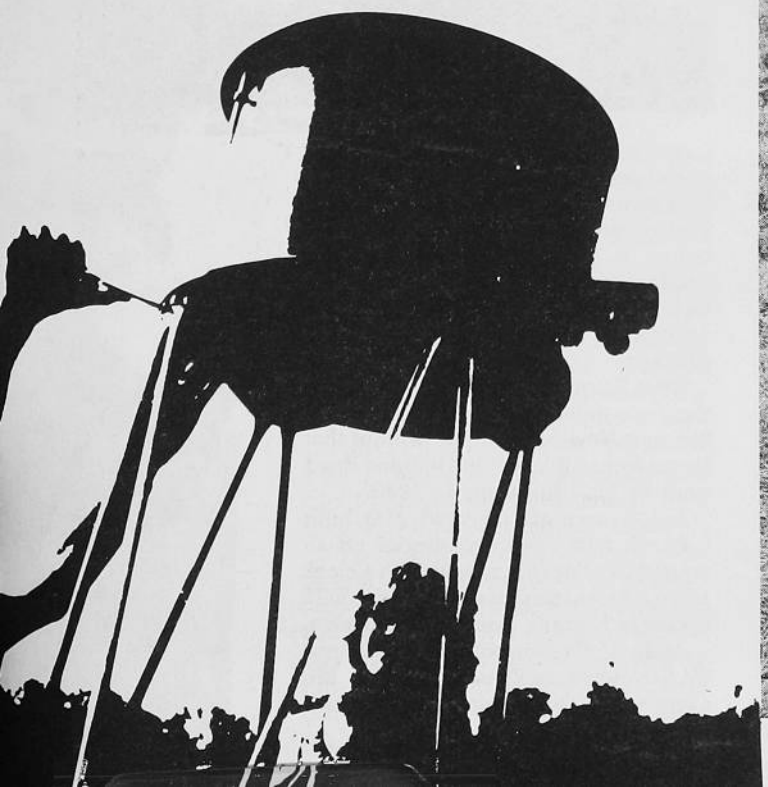


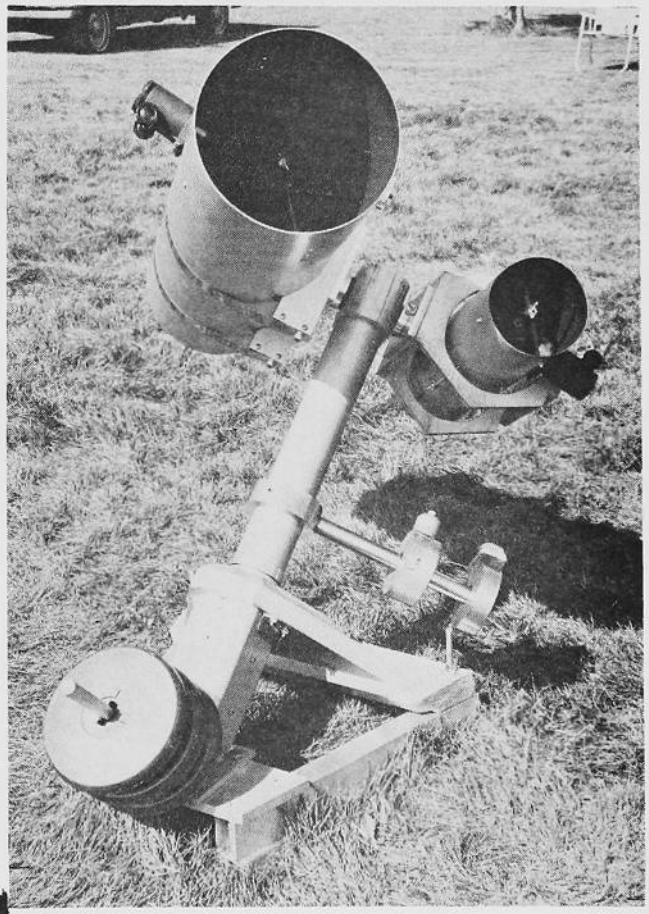
Tom Burns built this portable "Boppian" reflector around a 17.5" mirror.

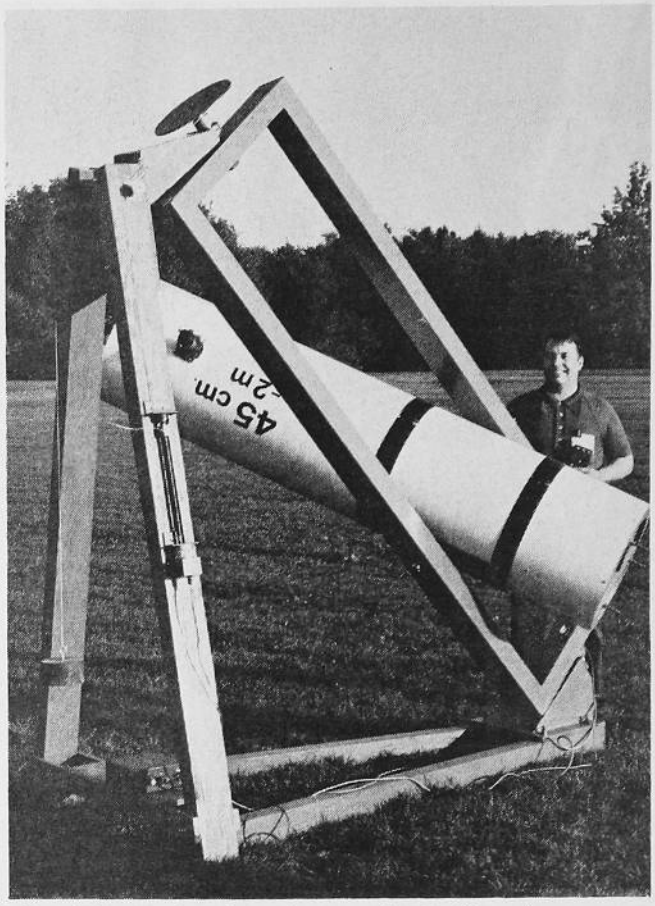


Closeup shows light baffle.

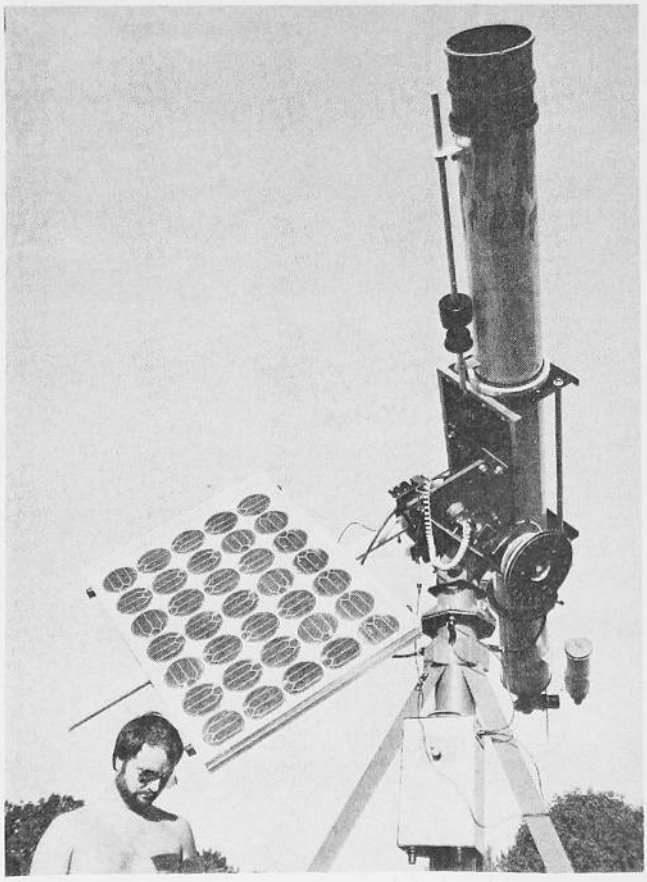
Ehrlich Michael of Chicago provides continuous tracking across the meridian.



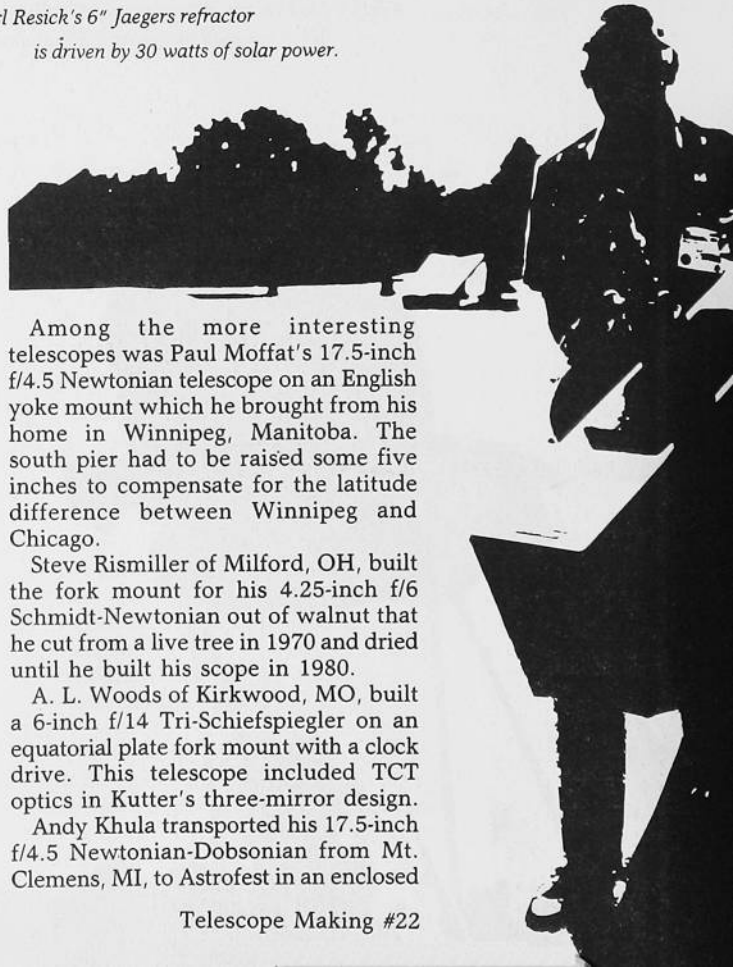




Richard Wessling exhibited his 8" f/20 Kotter Schiefspiegler, and Paul Moffat of Winnipeg brought a yoke-mounted 17.5" Newtonian.



Carl Resick's 6" Jaegers refractor is driven by 30 watts of solar power.

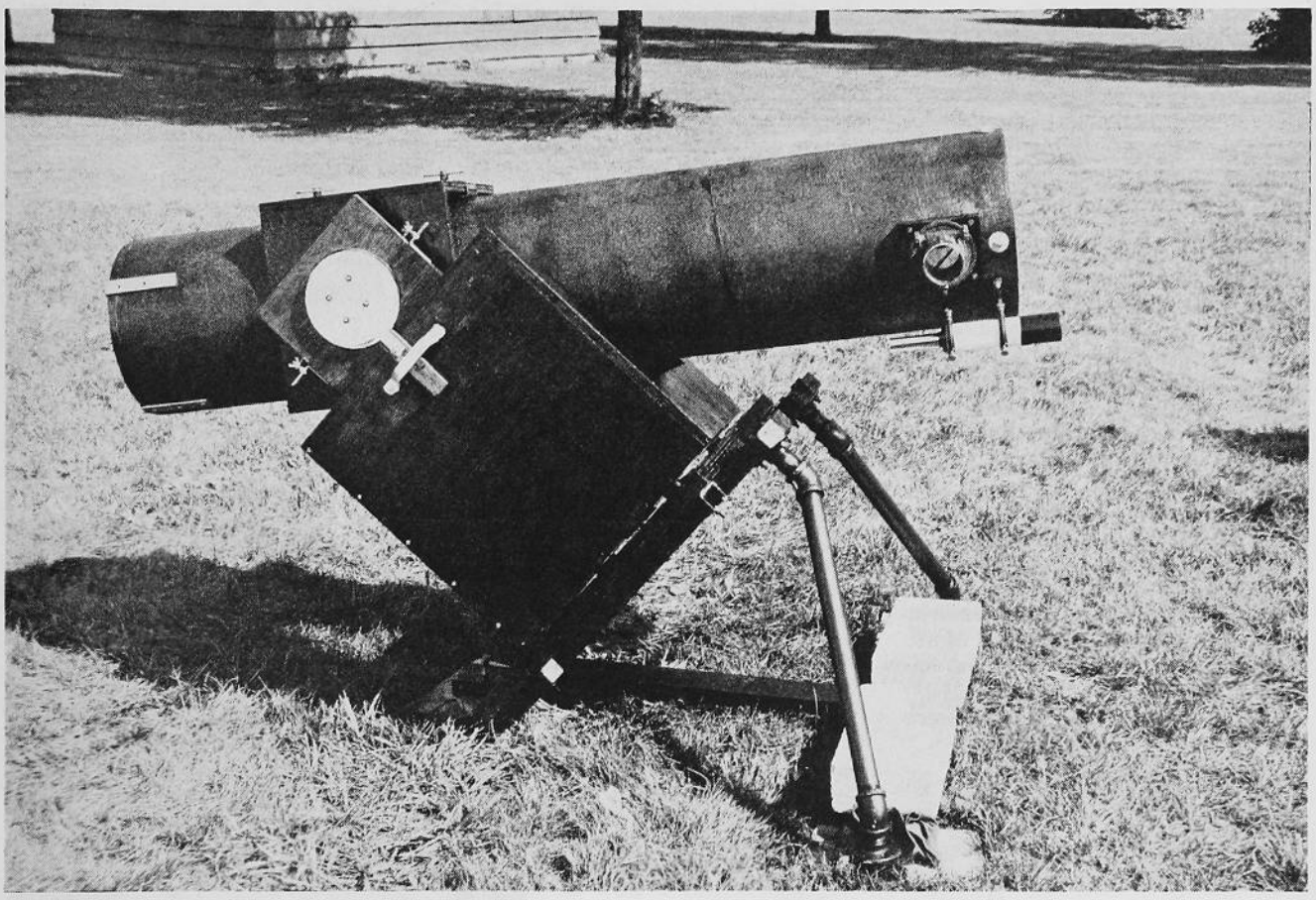


Among the more interesting telescopes was Paul Moffat's 17.5-inch f/4.5 Newtonian telescope on an English yoke mount which he brought from his home in Winnipeg, Manitoba. The south pier had to be raised some five inches to compensate for the latitude difference between Winnipeg and Chicago.

Steve Rismiller of Milford, OH, built the fork mount for his 4.25-inch f/6 Schmidt-Newtonian out of walnut that he cut from a live tree in 1970 and dried until he built his scope in 1980.

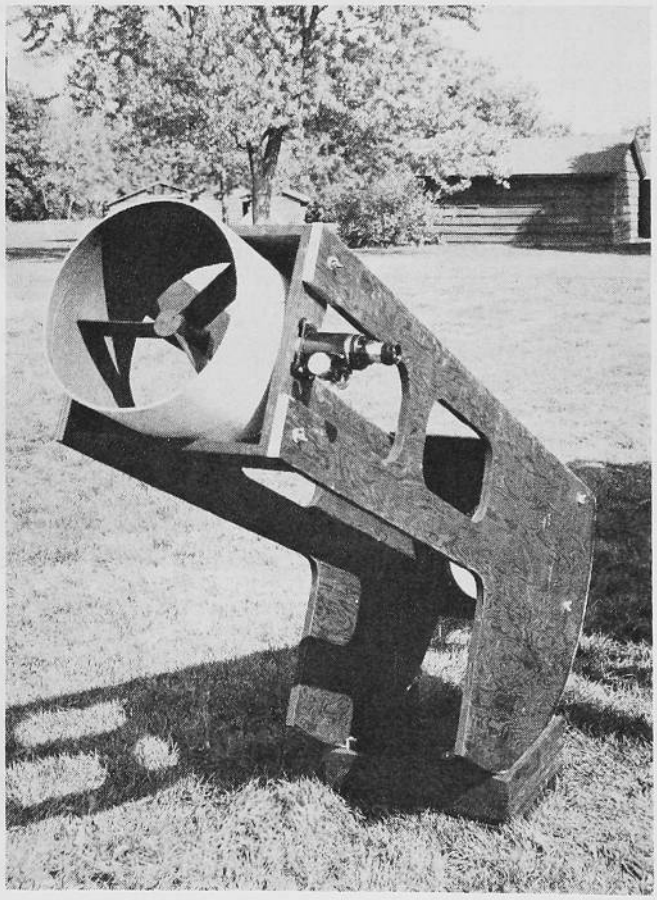
A. L. Woods of Kirkwood, MO, built a 6-inch f/14 Tri-Schiefspiegler on an equatorial plate fork mount with a clock drive. This telescope included TCT optics in Kutter's three-mirror design.

Andy Khula transported his 17.5-inch f/4.5 Newtonian-Dobsonian from Mt. Clemens, MI, to Astrofest in an enclosed



Phillip Chemley converted his Dobsonian to an equatorial. Note counterweights!

Chuck Thompson's "Thompsonian" features a 12" mirror in a fully collapsible telescope.



aluminum trailer. Along the way, the trailer broke loose from the hitch and flipped over a few times! The telescope was only slightly damaged, though the trailer showed a few dents. After welding the tow-bar back on, Mr. Khula continued on to Astrofest.

The afternoon brought two papers, "Those Schiefspiegler Optics Aren't So Tough" (Richard Wessling) and "The Wanderers," a time-lapse movie of nine months of actual planetary motion by Chicago Astronomical Society president Carl Buzzard and former member Paul Lorenz, who now lives in Arizona.

The noted optician Robert Cox conducted a workshop on "Telescope Optics" giving his view on what was and was not worth doing with different types of telescope optics. Complementing Mr. Cox's workshop, Richard Berry conducted a workshop on "Telescope

Mountings."

The Saturday evening meal was again a catered affair: chicken and roast beef, plus a variety of salads and deserts. After dinner, Rollin P. Van Zandt, former president of the Astronomical League, member of the Peoria Astronomical Society, and a major force in the construction of the P.A.S. observatories, spoke on "Large Optical Telescopes of the Future," detailing the plans of professional astronomers for the next generation of large Earth-based telescopes.

After being dazzled by plans for 500-inch telescopes, our eyes were dazzled by the door prizes that were awarded. The telescope committee then awarded merit certificates to the best and most original telescope designs.

The clear skies returned as the assembled telescopes were once again put to good use. "Observing-poopers" were treated to the science fiction movie classic *Robinson Crusoe on Mars. Stranger than Science Fiction*, about the early space age, and *Mars Minus Myth*, about the Viking probe of Mars, were also presented.

Once again, observing continued far into the early morning hours. Views included the Orion Nebula, the Pleiades, and a host of other winter-sky objects. The waning crescent Moon did not rise until long after midnight.

Sunday dawned bright, but most attendees did not crawl out of bed until much later. Even then, most of those partaking of the coffee and doughnut breakfast were still groggy after a long night's observing. As they ate, they discussed the various telescopes they had seen, the objects they had viewed, and the things they had learned.

Noon brought with it the official end of Astrofest, and with it the last telescope left the site strangely deserted and quiet, but the memory of the best Astrofest ever would draw the observers back again on September 21, 22, and 23, 1984 for the next annual Astrofest, which would again bring amateurs together to share their hobby with each other.

— text by Berton Stevens
reprinted from the *CAS Observer*
newsletter of the
Chicago Astronomical Society

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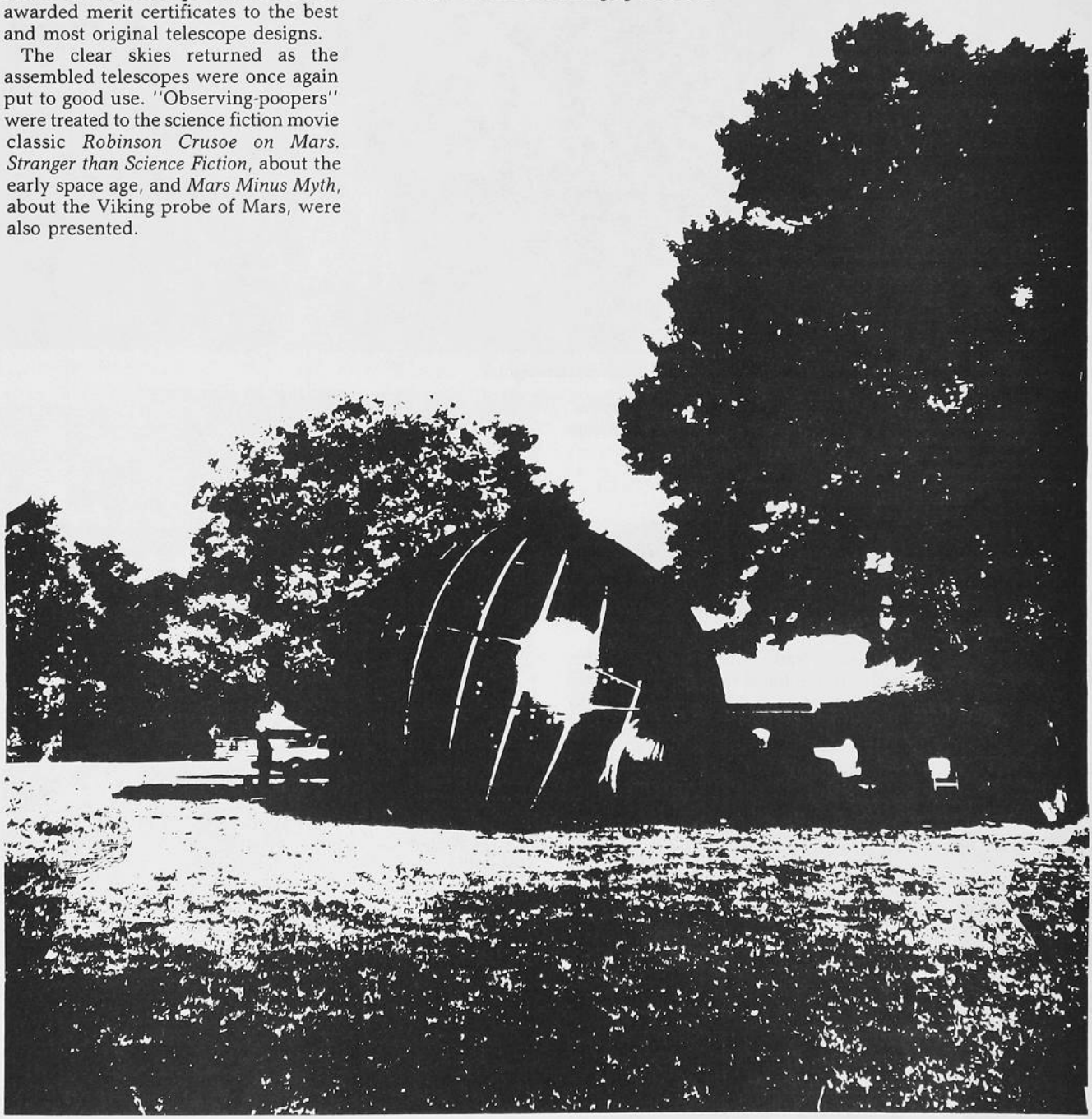

Letters
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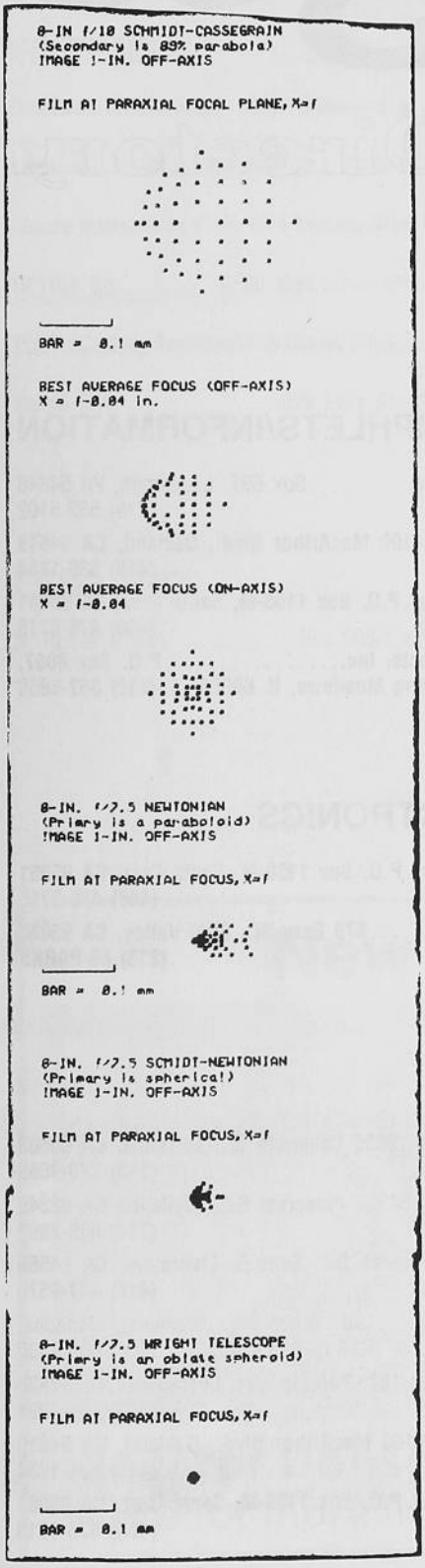
spot diagrams which show the off-axis performance of a number of different optical systems obtained on a $300 SHARP PC-1500 A pocket computer and its unit four-color printer/plotter.



As can be seen, these diagrams are quite informative and conclusive, and the best thing of all is that it probably took the computer less time to generate them than it took Mr. Gregory to manually plot his H'tanU' results.

There are many methods available with which to obtain reliable information on image quality of optical systems. Rather than being exclusive (as some people think), they tend to complement each other. With today's affordable technology, it is only the lack of software that prevents amateurs from enjoying the rewards and fascination of optics.

The real problem, then, that an amateur interested in optical analysis is likely to face is where to find the mathematics necessary for adequate ray tracing and how to use it — rather than the lack of time or good and affordable equipment.

In view of this, I believe it would be of great benefit to the readers if TELESCOPE MAKING published easy-to-follow instructions on ray tracing techniques. These articles would have to be followed by others on how to correctly interpret the data obtained, which is equally important. Geometrical ray tracing is limited in its capacity to predict the image quality in all cases, especially of systems with pronounced coma and diminished contrast.

Since TELESCOPE MAKING is oriented toward makers of telescopes (as its name suggests), I feel the articles which appear in it ought to enable its readers to duplicate the results, and ray tracing should not be an exception. In order to achieve this, TM should insist that its articles be presented not as simple facts, but rather as step-by-step procedures which readers can follow and thus benefit from — not merely in an academic but a pragmatic sense as well.

Mladen Vranjican
63-141 Alderton Street
Rego Park, NY 11374

— John Gregory writes: "In the past, when fewer designers had spot diagram programs, H'tanU' was even more important. When everyone has spots, H'tanU' will still have utility, still be quicker, and still show more clearly what's happening — unless you happen to have a full field of through-focus spot diagrams from a half-pupil aperture."

Having written a program that computes mirror aberrations and throws resulting spot diagrams on the computer screen fast enough that you can watch the rays roll through focus, I now find static spot diagrams something of a bore. They don't show where the worst rays come from; in this respect, the H'tanU' plot has useful information that static spots really don't show. All the information necessary to plot the H'tanU' curve is present in the spot diagram — it's just a matter of extracting it and plotting it beside the spot diagram — so you might as well have both. Incidentally, Gregory adds that "home optical design programs are now on the market for many microcomputers. Mike Jones is now writing one for the Commodore 64."

What you would like to see in TM is a tall order, indeed. I am inclined to think that a book would be the best format for the discussion you have in mind, but I certainly would not discourage anyone who offered to write such a series for TM.

Air Cell Support?

Dear Mr. Berry / While I was reading about mirror cells, I got an interesting idea: If you have a large and thin mirror, you need a flotation cell, don't you? Such cells are usually complicated to make. Why not instead make a simple, flat-bottom cell, take a piece of sealed-air plastic sheet, lay it on the bottom of the cell, and rest the mirror on it. The mirror will now lay on many small "air chambers" which should act as flotation points. It sounds nice, but would it work? Unfortunately, I've been unable to find a thin and big mirror here. Maybe one of your readers will try the idea and drop you, or me, a letter?

Ziljho Andreic
Snorcorn 22
4100 Zagreb
Yugoslavia

— I don't think it will work as a flotation cell because each little air bag is independent, and therefore cannot sense whether it is pushing too much or too little on the back of the mirror. If the cells were interconnected, then the mirror really would float. Perhaps someone will give it a try anyhow, and let us know whether it works.

АКАДЕМИЯ НАУК СССР

ИНСТИТУТ НАУЧНОЙ ИНФОРМАЦИИ

1.51.13. Большой телескоп лорда-Росса. Dick Thomas. Lord Rosse's great telescope. «Telescope Mak.», 1980, № 7, 8—13 англ.)

Статья перепечатана из «The Practical Astronomer» (1859 г.) Описаны конструкция и история создания в первой половине 40-х гг. XIX в. крупнейшего рефлектора лорда Росса. Зеркало диаметром 1,8 м было отлито из спекула-металла (сплав меди и олова в отношении 126,4:58,9). Подробно рассказано о процессе отливки и полировки зеркала, приведены рисунки монтировки телескопа. Уже первые наблюдения подтвердили высокие качества инструмента. Дано краткое описание наблюдений туманностей, звезд и Луны, проведенных при помощи телескопа Росса. Г. Р.

4.51.867. Обсерватория Гоулден Ридж. Happe Norman L. Golden Ridge Observatory. «Telescope Mak.», 1980, № 8, 34—36 (англ.)

Любитель астрономии подробно рассказывает о создании небольшой и сравнительно дешевой башни для маленького компактного телескопа (Celestron-8 или 5" самодельного рефрактора). При необходимости башня может быть разобрана и перенесена на другое место. Приводятся фотографии и план башни.

2.51.1026. Передача контраста и разрешающая сила визуальных телескопов. Contrast rendition and resolving power in telescopes used visually. Van Venrooij M. A. M. «Telesc. Mak.», 1982, № 16, 5—9 (англ.)

Популярно изложено понятие частотно-контрастной характеристики (ЧКХ) оптических систем, приведены ЧКХ идеального и нендеального телескопа, рассчитаны ЧКХ и параметры дифракционной картины при центральном экранировании 0; 0,25 и 0,50. Показано, что при визуальных наблюдениях разрешение зависит от типа объекта: если для двойных звезд центральное экранирование слегка повышает разрешение, то для объектов малоконтрастных разрешение, наоборот, падает при экранировании, причем при разном уровне освещенности разрешение тоже будет разным. Библ. 8. А. Т.

2.51.1031. Постройка трехзеркального телескопа Каттера. Building a Kutter 3-Mirror Tri-schiefspiegler. Woods A. L. «Telesc. Mak.», 1982, № 16, 10—17 (англ.)

Описано изготовление в любительских условиях 15 и 20 см телескопов из трех наклонных сферических зеркал. К этой системе, впервые рассчитанной Каттером (A. Kutter), внеосевые аберрации зеркал взаимно компенсируются, а зрачок не экранируется. Приведены расчетные параметры оптической системы, допуски на качество поверхностей, на точность углов и взаимных расстояний зеркал (в этом отношении телескоп Каттера предъявляет гораздо более жесткие требования, чем обычные системы). Подробно описаны способы изготовления корпуса телескопа и оправ для зеркал. А. Т.

2.51.1032. Юстировка трехзеркального телескопа Каттера. Collimation for a Kutter Tri-schiefspiegler. Woods A. L. «Telesc. Mak.», 1982, № 16, 18—21 (англ.)

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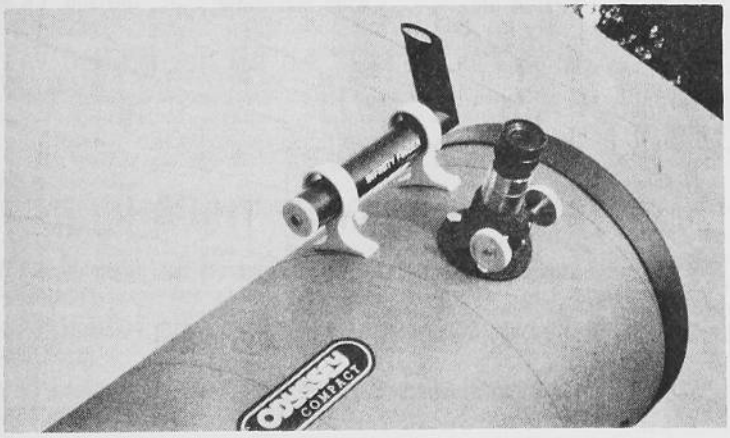

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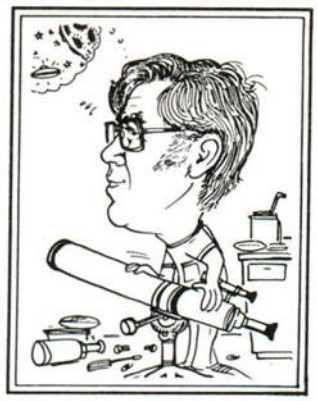

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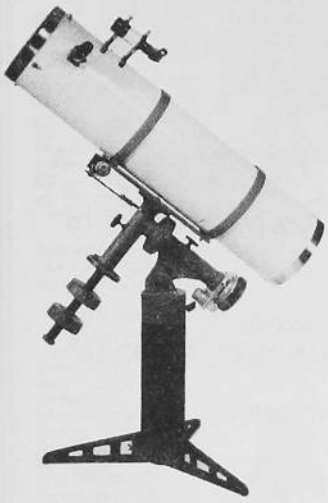

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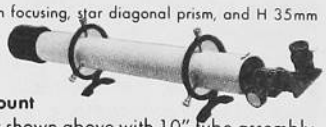

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46, 48, 49mm	$29.95	$25.00
52, 55, 58, 62mm	$39.95	$29.95
67, 72, 77mm	$46.95	$39.95
82mm	$49.95	

Hypered 2415 film, 36 exp . . . $9.95 . . . 3/$27

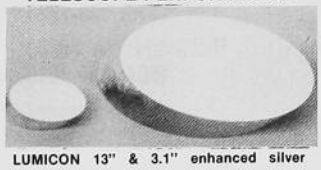
SUPER-FINDER™

The LUMICON SUPER-FINDER is both a compact Rich-Field Telescope and a magnificent "Super-Finder". It has a fully coated 80mm achromatic lens and 300mm focal length. The Deluxe SUPER-FINDER has a superb 500mm f/6 air-spaced lens.

10X80mm SUPER-FINDER $149.95
1¼" SUPER-FINDER w/o eyepiece . $129.50
1¼" Right-angle SUPER-FINDER* . $129.50
2" SUPER-FINDER w/ 1¼" adapter . $139.50
2" Right-angle SUPER-FINDER* . . . $169.50
1¼" DELUXE SUPER-FINDER* $199.50
2"/1¼" DELUXE SUPER-FINDER* . $249.50
**Requires a 1¼" or 2" star diagonal*

1¼" star diagonal, 30mm aperture . . $26.95
2" LUMICON mirror-type star diagonal, threaded for 48mm filters . . . . . **add $89.50**
Mounting rings, 3-5/8" I.D $16.95/pair
Mounting adapter for C-8, Meade etc . . . $35

NEW! ENHANCED SILVER DIAGONAL MIRRORS BOOST TELESCOPE PERFORMANCE



LUMICON 13" & 3.1" enhanced silver diagonals.

The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed pyrex flat to 1/8 wave.

Diagonal Size	Price
1.32" Minor axis	$29.95
1.52" Minor axis	$34.50
1.83" Minor axis	$39.50
2.14" Minor axis	$47.50
2.60" Minor axis	$59.50
3.10" Minor axis	$79.50
4.25" Minor axis	$129.50

ENHANCED SILVER STAR DIAGONALS

LUMICON 2" Star diagonal with enhanced silver mirror.

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.

1¼" (1.32" mirror) $79.50
2" (1.83" mirror) (see photo above) . . $119.50

LOW PROFILE NON-ROTATING HELICAL FOCUSER

LUMICON® DELUXE NON-ROTATING HELICAL FOCUSER on a SUPER-FINDER. LUMICON has just designed a deluxe smooth helical focuser with non-rotating 2" I.d. eyepiece holder. It has a vertical travel of 1¼" and a very low profile only 1¼" high. It is CNC machined, black anodized, and a perfect match to a LUMICON Newtonian EASY-GUIDER.

Select your desired base-plate shape!
Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 20" OD, SUPER-FINDER base plate.

LUMICON Deluxe Helical Focuser . . $69.50
3 handles (see photo) $12.95
Helical focuser with 3 handles $79.95
2"/1¼" adapter w/48mm filter threads $16.95
2" LUMICON EASY-GUIDER $139.50

NEW! GIANT LUMICON® DEEP-SKY FILTERS

48mm, 58mm, 72mm DEEP-SKY Filters

LUMICON now offers its high performance **DEEP-SKY Filters** in larger sizes. They allow **both** color & B&W photography with larger telescopes. Light pollution is reduced 3-6 fold, stellar images improve and emission nebulae have increased red contrast.

DEEP-SKY FILTER	PRICE
48mm (46, 49, 52mm add $6.95)	$99.50
58mm (55, 62mm add $6.95)	$129.50
72mm (67, 77mm $6.95)	$149.50

MAKE YOUR OWN ASTROGRAPH

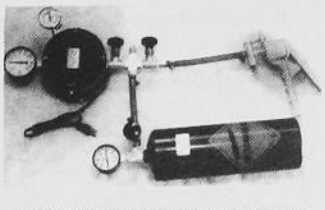
FILM HYPERSENSITIZATION KITS†

LUMICON HYPER-KITS™ yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

†Patent Pending

MODEL 100 HYPER-KIT for 35mm film, rolled-up. *Takes longer,* but it easy to use. Not recommended for 2415 . . . . . $225.00

MODEL 300 HYPER-KIT sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds $275.00



MODEL 600 HYPER-KIT [See Photo] Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates $299.50

MODEL 1200 HYPER-KIT is for 4X5" plates and film up to 5X7". Has 2 gas cylinders and includes temperature controller . . . $525.00

Temperature controller for any HYPER-KIT $59.50

Electric Vacuum Pump $265.00

GUIDE OFF-AXIS FOR LOVELY ASTROPHOTOS

All **LUMICON EASY-GUIDER**™ off-axis guiders† have both radial and 360° rotational adjustments for 5X eaiser guide-star selection, use 48mm filters, 360° camera rotation, large prisms fo bright guide-starts. *Specify Camera and Telescope type.*

†Patent Pending

NEWTONIAN EASY-GUIDER™

Full aperture. Installs in secs. Specify 2" or 1¼".
NEWTONIAN EASY-GUIDER $139.50
3X Relay Diagonal [See Photo] $59.50
Illuminated reticle eyepiece system . $59.50

CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**
CASSEGRAIN EASY-GUIDER $199.50

GIANT EASY-GUIDER™

For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**
GIANT EASY-GUIDER $359.50
48mm DEEP-SKY Filter ordered with any EASY-GUIDER [SAVE $20] . . . . . **add $79.95**

WHAT DO YOU NEED?

1. Hypersensitized Film. Use a LUMICON HYPER-KIT to insure a fresh supply, or use film pre-sensitized by LUMICON.
2. LED Illuminated reticle eyepiece system and battery pack, dual crosslines . . . $59.50
3. Telescope with good drive. (See above)
4. Piggyback adapter (state telescope type) . . . $25 Deluxe adjustable $39.50
200mm f/3.5 multicoated lens $99.95
5. Filtration is essential for all lenses. Use hypered 2415 and the H-Alpha Pass Filter. For III a-J or color, use the Minus Violet Filter or the LUMICON DEEP-SKY Filter.
6. Off-axis guider is **essential** for consistently good prime-focus astrophotography.
7. Dual-axis drive corrector and electric declination (state telescope type) $259

HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. For fine grain B&W film use 2415. The fastest color films are Fujichrome 400 for slides and Kodak VR1000 for prints. Use VR1000 for galaxies and Fujichrome 400 for nebulae.

Film Type (35mm unless marked)	Exposures	Price
2415, Ultra-fine B&W, red sens	36	$9.95
Ektachrome 200 prof. 5036	20	$9.95
Fujichrome 400, "Excellent"	20	$12.95
VR1000, fastest of all, color negs	12	$12.95
5072, color slides from negs	36	$6.95
D-19 B&W Developer, 1 gal.		$5.95

TELE VUE™ EYEPIECES USE THE BEST!!

Plossl, Wide-Field, Nagler Eyepieces

Tele Vue Plossl eyepieces have a sharp 50° apparent field-of-view. The Wide-Field eyepieces have a 65° field-of-view and are sharper than Erfle and Konig Eyepieces. The revolutionary Nagler eyepieces are sharp clear to the edge of a giant 82° field-of-view. **The eyepiece is half the telescope — use the best!**

7.4, 10.4, 13, 17, 21, 26mm Plossl(50°) . . . $65
2½X Tele Vue Barlow Lens $65
32mm Plossl, widest true field in 1¼" . . $80
55mm 2" Plossl, widest possible field . $160
19mm Wide-Field, 1¼" eyepiece (65°) . $110
24mm Wide-Field, "superb" (65°) $125
32mm Wide-Field, 2" eyepiece (65°) . . . $195
40mm Wide-Field, "awesome" (65°) . . . $250
4.8mm Nagler, 82° field $125
9mm Nagler, 82° field, "the best" $195
13mm Nagler, 82° field, 1¼" or 2" $220
(apparent field of view in parenthesis)

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(complete telescope tube assembly with front cell, rear cell, tube, focusing assembly, finderscope, aligned/tested optics, carrying case.)

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5" optical tube assembly $675
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8" optical tube assembly with Mgf2 on corrector lens $800
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Matching Deluxe Barlow Lens—2X $60
Eyepiece Filter Set (6 filters) $50

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25mm Orthoscopic $115
32mm Erfle $115
40mm Orthoscopic $115
50mm Plössl $115
60mm Kellner $95
70mm Kellner $95
2" Diagonal (threaded to fit Celestron universal threads) $200
Barlow Lens—2"—2X $60
Eyepiece filter set—2" $80

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10x40 with bracket $100
10x70 with bracket $200
5x24 right angle finderscope $40
6x30 right angle finderscope $45
8x50 convertible rt. angle/straight $100

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IC controlled with variable adjustments for lunar, planetary and sidereal rates.
DC inverter $80
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(extra power for a C14 and outlet for Cold Camera)

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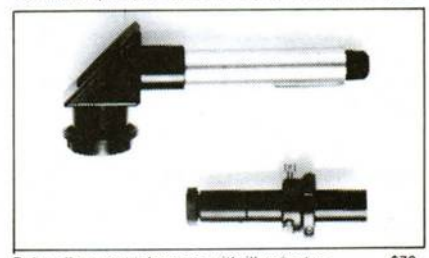
Astrofilter (red #2S) $35
Off-axis guiding body $60
Permanent pier (for C5/C8/C11/C14) $550



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(crosshair illuminator)

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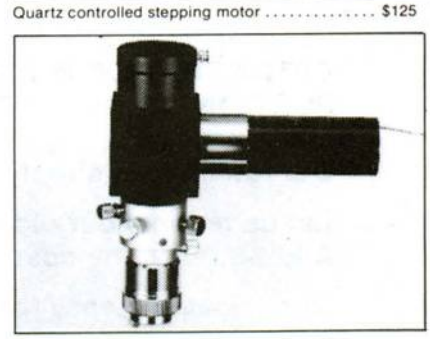

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"Used with my 12" f/7, the Plössls deliver crisp images of the planets. I have the distinct impression that the eyepiece adds no optical errors to the image I'm viewing, and that I am seeing everything the mirror can deliver. This is an impression I've never had with any other eyepiece. Tele Vue Plössls are the sharpest I've ever used." — From review in August '81 "Astronomy"

New 4 element design improves performance of any telescope. Exceptional contrast and resolution over the entire 50° field, even with fast Dobsonians. Ideal for astrophotography too. Multi-coated. Chromed barrels threaded for filters.

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40mm	80
32mm	80
26mm	65
21mm	65
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13mm	65
10.4mm	65
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2.5x	65

Tele Vue 65°
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A MAJOR NEW ADVANCE!

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24mm	125
19mm	110

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Patented 7-element design introduces a new dimension in observing. Dramatically more field, sharpness and eye relief than any commercial eyepiece. Multi-coated. Dynamite with Dobsonians.

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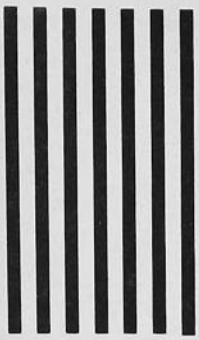
RULED GRATINGS FOR RONCHI TEST



The Ronchi Test has been used for many years as a quick qualitative method to evaluate overall mirror surface smoothness and figure. We stock 85 and 133 line gratings with equally spaced opaque lines that occupy 50 percent of the total area. The grating is a highly accurate photographic reproduction on a thin, transparent, and durable film. The thin film base minimizes annoying diffraction effect common to thick glass substrates. We recommend the 85 line grating for preliminary evaluation and the 133 line grating for final inspection.

☐ 85 Line Grating 2"x2" **$2.50**
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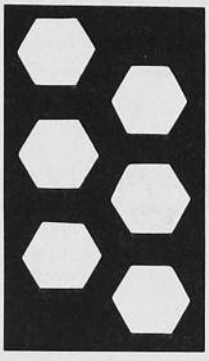
A low cost, time proven tool. Do what professionals do for large surfaces. Use our 1" hexagonal optical grade ceramic to make a low cost tool on a backer of metal, stone, or wood. Ideal for 10" or larger mirrors where tool is costly if made of glass or Pyrex. In addition to low cost, the open channels of a tool made with these tiles promotes much faster grinding with more economical use of abrasives. We have also found that flats grind out more easily and without turned edges. Epoxy glue is used to cement the tiles to the backer but is not supplied. Shipped with detailed instructions.



☐ 1 sq foot CERA-HEX-TOL ..... **$4.50 fob**

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40 Grit*	$ —	$ —	$3.75	$13.00
60	—	—	3.75	13.00
80	—	—	3.75	13.00
Silicon Carbide or Aluminum Oxide				
120 Grit	1.50	2.50	3.75	13.00
220	2.00	3.00	4.75	14.50
320	2.50	3.75	5.75	20.00
500	3.00	4.75	6.75	22.50
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Black Rouge	1.75	2.75	4.50	15.50
Rosin	1.75	2.50	4.75	15.00
Burgundy Polishing Pitch				
Hard	—	3.25	5.75	18.00
Medium	—	3.25	5.75	18.00
Soft	—	3.25	5.75	18.00
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Beeswax	3.50	6.50	11.00	—
Blocking Pitch				
Hard	3.50	5.50	7.50	—
Medium	3.50	5.50	7.50	—
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*Grit = Number of grains laid end to end = 1"
**Micron = 1 micron = 1 millionth of a meter

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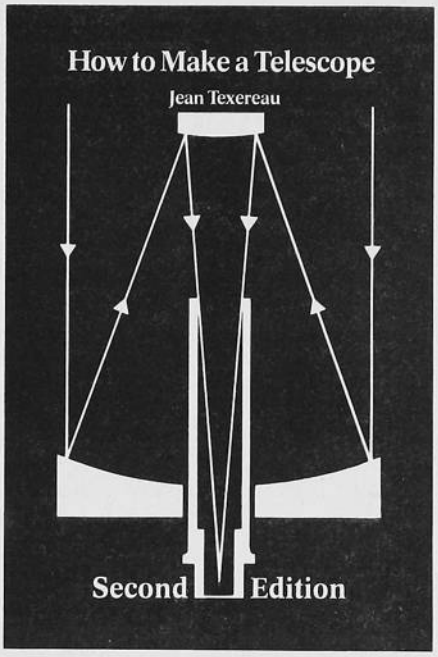

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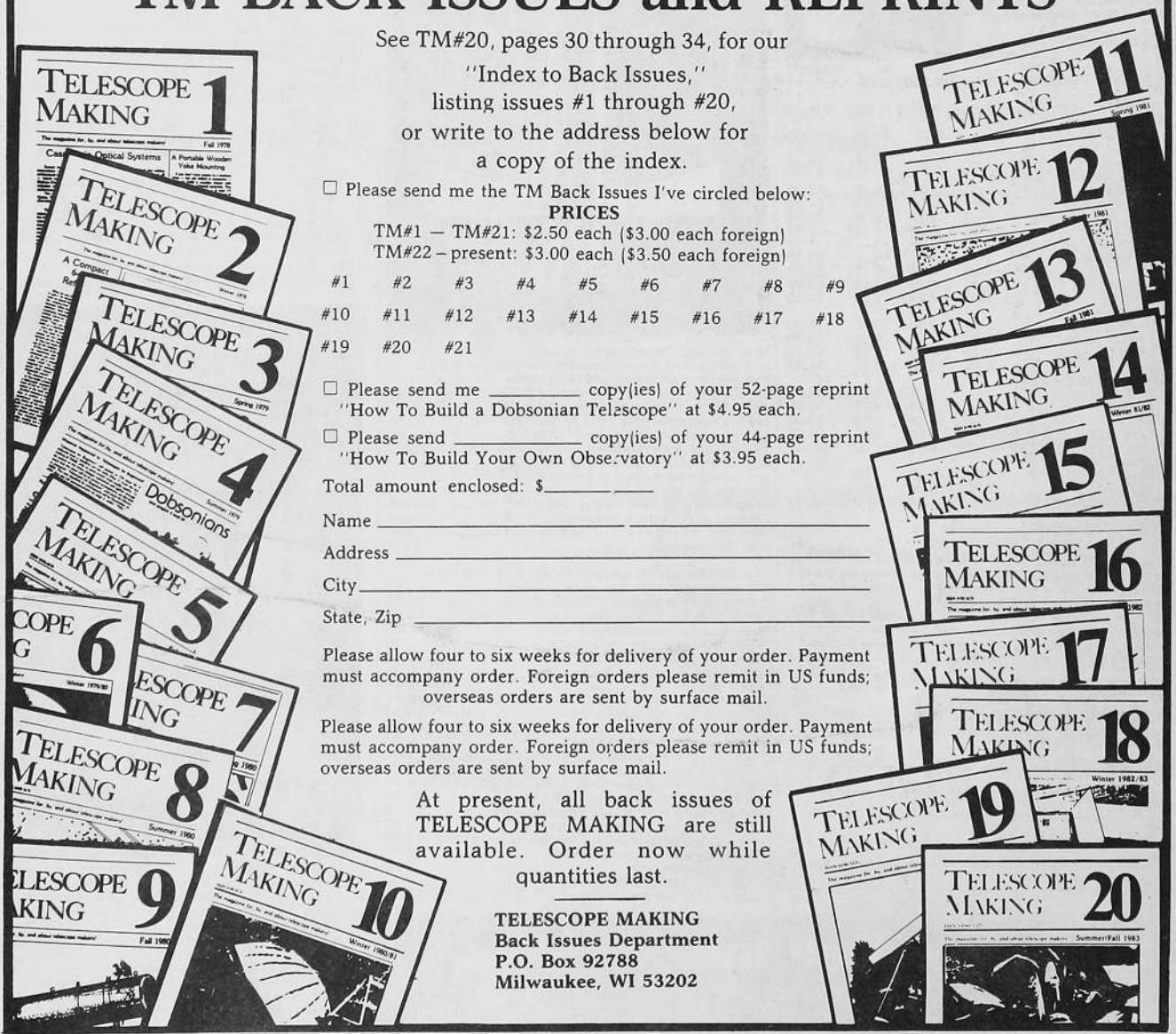

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